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Neighborhood Socioeconomic Environment and Its Influence on Cardiorespiratory Fitness and Physical Activity in Youth

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ABSTRACT

Among youth, inadequate cardiorespiratory fitness and physical inactivity are powerful markers of health associated with numerous health outcomes across the lifespan. Unfortunately, a majority of U.S. youth have inadequate cardiorespiratory fitness levels and do not meet physical activity guidelines. While previous research has identified several individual-level factors associated with youth cardiorespiratory fitness and physical activity, environmental factors have been increasingly recognized. Of particular interest is the neighborhood socioeconomic environment, which has been consistently associated with several health outcomes among adults. However, little is known regarding the relationship between the neighborhood socioeconomic environment, cardiorespiratory fitness, and physical activity among younger populations. Hence, the overall purpose of this dissertation was to determine how characteristics of neighborhood socioeconomic environment are associated with cardiorespiratory fitness and physical activity in diverse samples of youth. Three studies were conducted to address this overarching purpose.

In study one, the relationship between cardiorespiratory fitness and area-level socioeconomic environment was examined. The extent to which sex, grade level, race/ethnicity, and family socioeconomic status moderated this relationship was also examined. Results indicated that cardiorespiratory fitness was positively associated with area-level socioeconomic environment among school-age youth in South Carolina. More

specifically, the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness decreased by approximately 25-34% with increasing deprivation of the socioeconomic environment, after controlling for covariates. Additionally, the association between cardiorespiratory fitness and area-level socioeconomic environment varied significantly by sex, grade level, and race/ethnicity.

Study two investigated the association between cardiorespiratory fitness and neighborhood socioeconomic environment; and examined the extent to which physical activity mediated this relationship in a nationally representative sample of U.S. youth. The findings from this study indicated that neighborhood socioeconomic environment was not significantly associated with cardiorespiratory fitness or physical activity. While non-significant, cardiorespiratory fitness was observed to decrease as deprivation of neighborhood socioeconomic environment increased. It is plausible that limitations in the study design and/or lack of statistical power may have contributed to the null findings.

The purpose of the study three was to describe the longitudinal association of neighborhood socioeconomic environment with physical activity in youth during the transition from childhood to adolescence, and to determine if access to physical activity facilities moderated this relationship. Findings demonstrated that changes in physical activity from 5th grade to 7th grade were significantly associated with neighborhood socioeconomic environment. Over time, decreases in physical activity varied by degree of neighborhood socioeconomic deprivation. However, access to physical activity facilities did not moderate this relationship.

In conclusion, the findings of this dissertation suggest that neighborhood socioeconomic environment is associated with cardiorespiratory fitness and physical activity in youth. In general, increased deprivation of the neighborhood socioeconomic environment was associated with lower cardiorespiratory fitness and physical activity levels in youth. However, some inconsistencies were observed across the findings of the three studies. Additional studies are needed to better understand the complex relationships among neighborhood socioeconomic environment, cardiorespiratory fitness, and physical activity in youth.

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CHAPTER 1

OVERALL INTRODUCTION

Overall Introduction

Poor physical fitness and physical inactivity are well-documented risk factors of chronic disease and premature death (1–3). Cardiorespiratory fitness is considered to be one of the most important markers of health and a strong predictor of morbidity and mortality for cardiovascular diseases and all-cause mortality (4–8). Habitual physical activity is recognized as one of the primary modifiable determinants of cardiorespiratory fitness (9, 10). Among youth, strong evidence suggests that cardiorespiratory fitness is already a powerful marker of health that is significantly associated with cardiometabolic health in adulthood (10–16). Unfortunately, a majority of U.S. youth do not have adequate levels of cardiorespiratory fitness and do not meet the physical activity guidelines according to the most recent surveillance data (17, 18).

Previous research has identified several individual-level characteristics that are associated with cardiorespiratory fitness and physical activity in youth (11, 19–24). However, environmental factors have been increasingly recognized as important influencers on health-related behaviors and outcomes (25–27). Recent studies have highlighted the importance of the socioeconomic environment in influencing health (27–31). This growing body of evidence has consistently reported a significant association between neighborhood socioeconomic environment and numerous health outcomes including mortality, cardiovascular disease, cancer, depression, and other chronic disease risk factors (26, 32, 33). More specifically, findings from previous studies suggest that individuals residing in disadvantaged neighborhoods (i.e., poor neighborhood socioeconomic environment) are less likely to engage in health-enhancing behaviors and are more likely to experience poorer health outcomes than individuals residing in more affluent neighborhoods (32, 34–37).

To date, limited research has examined the relationship between neighborhood socioeconomic environment, cardiorespiratory fitness, and physical activity among younger populations (38–48). The findings across previous studies have been mixed and vary considerably based on the methodology and measurements employed. Hence, the independent influence of the neighborhood socioeconomic environment on cardiorespiratory fitness and physical activity among youth remains relatively unknown. Further, few studies have examined how individual-level characteristics and the built environment interact with neighborhood socioeconomic environment to influence youth cardiorespiratory fitness and physical activity levels.

As such, the overarching purpose of this dissertation was to describe how characteristics of neighborhood socioeconomic environment are associated with cardiorespiratory fitness and physical activity in diverse samples of youth. Based on existing literature, it was hypothesized that the neighborhood socioeconomic environment would be significantly associated with cardiorespiratory fitness and physical activity levels in youth. Specifically, it was hypothesized that lower physical activity and cardiorespiratory fitness levels would be observed among youth residing in neighborhoods characterized by poor socioeconomic environments (i.e., areas of concentrated deprivation). Three existing data sources that contained measures of youth cardiorespiratory fitness and/or physical activity were combined with publicly available census data to advance the hypotheses in this dissertation project.

Study one examined the relationship between cardiorespiratory fitness and socioeconomic environment in a diverse sample of school-aged youth using data from the South Carolina FitnessGram project. First, the independent association between the socioeconomic environment and cardiorespiratory fitness was examined, controlling for individual-level sociodemographic characteristics. Then interactions terms were introduced into the model to determine whether the relationship between socioeconomic environment and cardiorespiratory fitness was moderated by sex, grade level, race/ethnicity, and/or family socioeconomic status.

Given the established relationship between cardiorespiratory fitness and physical activity, study two aimed to determine whether physical activity mediated the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness. Data from the NHANES National Youth Fitness Study provided a nationally representative sample of youth (12-15yo). The independent association between neighborhood socioeconomic environment and cardiorespiratory fitness was examined, controlling for individual-level characteristics. Next, the extent to which physical activity mediated the relationship between neighborhood socioeconomic status and cardiorespiratory fitness was examined.

Finally, study three examined the relationship between the neighborhood socioeconomic environment, physical activity facilities, and changes in physical activity among a cohort of youth participating in the TRACK study. This study first examined the association between neighborhood socioeconomic environment and youth physical activity levels during the transition from childhood to adolescence. Next, the extent to which the presence of supportive physical activity facilities moderated the relationship between the neighborhood socioeconomic environment and changes in physical activity was examined.

Together, the results from these three studies address gaps in the literature and represent a logical step in understanding the influence of the neighborhood socioeconomic environment on factors associated with cardiometabolic health in youth. The findings presented in the following chapters expand our understanding of the relationships between neighborhood socioeconomic environment, cardiorespiratory fitness, and physical activity among youth**.** Collectively, the results of this dissertation highlight the importance of examining the influence of the neighborhood socioeconomic environment on health-related outcomes and behaviors during youth.

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CHAPTER 2

MANUSCRIPT ONE: ASSOCIATION OF AREA-LEVEL SOCIOECONOMIC ENVIRONMENT WITH CARDIORESPIRATORY FITNESS IN YOUTH[1]

[1] Clennin, MN, Colabianchi, N, Kaczynski, A, Sui, X, Pate, RR. To be submitted to *Medicine & Science in Sports and Exercise.*

Abstract

Background. Cardiorespiratory fitness is one of the most important markers of cardiometabolic health and is a strong predictor of cardiovascular disease and all-cause mortality across the lifespan. However, little is known regarding the influence of area-level socioeconomic environment on cardiorespiratory fitness during childhood and adolescence. **Purpose.** To examine the relationship between area-level socioeconomic environment and cardiorespiratory fitness in a diverse sample of school-aged youth; and to determine the extent to which grade level, sex, race/ethnicity, and family socioeconomic status moderate this relationship. **Methods.** South Carolina FitnessGram data for school year 2015-2016 were obtained for 44,078 youth. Cardiorespiratory fitness was determined using PACER or 1-mile run/walk test. Area-level socioeconomic environment was expressed as a composite index score at the census tract level using data from the American Community Survey. Multilevel logistic regression analyses were conducted, controlling for individual-level characteristics and nesting within schools and districts. Interaction terms were then introduced to the model to examine their effect of multiple sociodemographic moderators. **Results.** Approximately half of the sample had inadequate cardiorespiratory fitness for health. The odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness decreased by approximately 25-34% with increasing deprivation of the area-level socioeconomic environment, after controlling for covariates. The association between area-level socioeconomic environment and cardiorespiratory fitness also varied significantly by sex, grade level, and race/ethnicity subgroups. **Conclusions**. Cardiorespiratory fitness was positively associated with area-level socioeconomic environment, however, the relationship varied by demographic

characteristics. These results highlight the importance of examining the influence of area-level socioeconomic environment on health across the life span. Additional research is needed to explore how area-level socioeconomic environment may impact evidence-based efforts to improve youth cardiorespiratory fitness levels.

Introduction

In the U.S., drastic inequalities in health have been observed across neighborhoods, zip codes, and counties (1–4). These persistent differences in health often remain after controlling for individual-level characteristics, suggesting that environmental-level factors play a role in influencing health. Existing literature has identified numerous characteristics of the physical and social environment within homes, neighborhoods, schools, and communities that are associated with health-related outcomes and behaviors (5–7). Additionally, elements of the socioeconomic environment have also been recognized as influential determinants of health and potential contributors to health inequalities beyond individual-level factors. Existing evidence suggests that area-level socioeconomic environment is independently associated with multiple health outcomes including cardiovascular disease, diabetes, and all-cause mortality (5, 8–11).

Previous studies have consistently demonstrated a positive relationship between area-level socioeconomic environment and cardiovascular disease and related health outcomes (12–17). However, little is known regarding its influence on indicators of cardiometabolic health, especially among younger populations. Among youth, cardiorespiratory fitness is regarded as one of the most important markers of cardiometabolic health and is a strong predictor of cardiovascular disease and all-cause mortality across the lifespan (18–21). Despite this evidence, there is a dearth of knowledge regarding the influence of area-level socioeconomic environment on cardiorespiratory fitness during childhood and adolescence. Across the few studies that have examined this relationship, the findings have been inconsistent (12, 14, 22). One study examined the relationship between community social vulnerability and cardiorespiratory fitness and found that schools located in more socioeconomically deprived areas had a lower proportion of youth with adequate of cardiovascular fitness levels (12). However, another study reported no significant variation in students' cardiorespiratory fitness levels by area-level socioeconomic environment of the school (22).

To date, the independent influence of area-level socioeconomic environment on cardiorespiratory fitness among youth remains relatively unexplored. While previous studies have consistently reported a positive association between area-level socioeconomic environment and cardiovascular health among adults (9, 10), it is unknown at what point during the life course the adverse impact of socioeconomic deprivation on cardiometabolic health emerges. Furthermore, the extent to which individual-level demographic characteristics moderate the relationship between area-level socioeconomic environment and cardiorespiratory fitness among youth has yet to be explored. Hence, the primary aim of this study was to examine the relationship between area-level socioeconomic environment and cardiorespiratory fitness in a diverse sample of school-aged youth. A secondary aim was to determine the extent to which the relationship between area-level socioeconomic environment and cardiorespiratory fitness varies across grade level, sex, race/ethnicity, and socioeconomic subgroups.

Methods

Data Source & Sample. Data were obtained from the South Carolina Department of Health and Environmental Control's (SC DHEC) FitnessGram project for school year 2015-2016. The SC DHEC FitnessGram project is a state-wide observational study to evaluate and ultimately improve health-related fitness among South Carolina students. All South Carolina public schools serving grades K-12 were eligible to participate. Participating schools conducted fitness testing and recorded health-related fitness data for students enrolled in physical education class. School staff received training support through the President's Youth Fitness Program prior to administering FitnessGram testing. All participating schools submitted data to the SC DHEC. The University of South Carolina received de-identified student-level data to assess health-related fitness among South Carolina students. Approximately 540 (38%) public schools across 47 (32%) school districts participated during school year 2015-216 (23). The analytic sample included 44,078 students in grades 5, 8, and 9-12.

Cardiorespiratory Fitness. Cardiorespiratory fitness was assessed using one of three field assessments: the Progressive Aerobic Cardiovascular Endurance Run (PACER) test, a 1-mile run test, or a 1-mile walk test. Additional information regarding the administration of the cardiorespiratory fitness field tests, validity and reliability of field tests, and the calculation of cardiorespiratory fitness are available in the FitnessGram manual (24). Briefly, the PACER test is a multistage, progressive fitness test that involves participants running at a specified pace for as long as possible. The 1-mile run and 1-mile walk tests are assessed using time to completion. For each test, cardiorespiratory fitness was estimated based on established protocols (24). Age- and sex-specific standards were then used to categorize cardiorespiratory fitness into one of three health zones: 1) Healthy Fitness Zone; 2) Needs Improvement; and 3) Needs Improvement – Health Risk. For all analyses, achievement of Healthy Fitness Zone for cardiorespiratory fitness (Yes/No) was modeled.

Area-level Socioeconomic Environment. Socioeconomic environment was expressed as a composite index score at the census tract level using data from the American Community Survey (ACS) 5-year estimates for 2011-2015 (25–27). Since student's neighborhood of residence could not be determined in the current dataset, school census tract was used as a proxy measure for area-level socioeconomic environment. Previous research has established an association between neighborhood of residence, school choice, and poverty such that the immediate and surrounding environment of the school reflects students' neighborhood environment (28, 29).The index was calculated using 20 census tract variables representing six domains for all South Carolina census tracts (Table 2.1) (25–27). Principal components analysis with varimax rotation was used to examine the data structure of the variables. The first common factor explained the greatest proportion of the total variance (43.1%) and included 11 variables with larger factor loadings (>0.25) on the first common factor (i.e., proportion of total population with less than a high school education, proportion of total population with a college degree, proportion female and male management occupations, proportion of population living below the federal poverty level income, proportion households with income $150,000+, median household income, median value of all owner-occupied households, proportion of households with low income, proportion of households with dependents that are headed by females, and proportion of persons living in same residence since 2005). Next, selected variables were weighted and standardized based on their variable loading coefficients and a composite index score was calculated by adding these values. Lower index scores indicate affluence or more favorable socioeconomic environments while higher index scores indicate more unfavorable or deprived socioeconomic environment. For all analyses, the area-level socioeconomic environment index was categorized into quartiles (Q1 [referent], Q2, Q3, and Q4).

Student Characteristics. Student sociodemographic characteristics were reported by school staff and/or were provided by the SC DHEC. Grade level was reported as 5^{th} grade [referent], 8^{th} grade, and high school (i.e., grades 9-12). Sex was reported as male [referent] or female. Race/ethnicity was expressed in the following groups: non-Hispanic white [referent], non-Hispanic black, Hispanic or Latinx, and other (including multiracial). Family socioeconomic status (high vs. low) was determined using student's poverty status on the 135 day of the school year based on enrollment in Medicaid, Supplemental Nutrition Assistance Program (SNAP), Temporary Assistance for Needy Families (TANF), or Foster Care Services within the past three years; and/or student homelessness/migrant status during school year. BMI was calculated from objectively measured height and weight and classified into weight status categories using CDC growth charts: underweight/normal weight ($<85^{th}$ percentile [referent]), overweight (85^{th} percentile to $<95^{th}$ percentile), and obese ($\geq 95^{th}$ percentile) (30).

Statistical Analyses. Descriptive statistics and bivariate associations between variables were examined. Multilevel logistic regression was used to examine the association between area-level socioeconomic environment and cardiorespiratory fitness. Cardiorespiratory fitness was modeled as achievement of Healthy Fitness Zone (Yes/No). Area-level socioeconomic environment consisted of four quartiles, as described above. All analyses accounted for the hierarchical structure of the data with students nested within schools and districts and controlled for grade level, sex, race/ethnicity, family socioeconomic status, weight status and fitness field test. Next, interaction terms were introduced to the model to examine the potential moderating effect of grade level, sex, race/ethnicity, and family socioeconomic status. To maintain a parsimonious model, only significant interactions were retained in the final model. Finally, stratified analyses were conducted by sociodemographic subgroups to interpret significant interactions. Linear and quadradic trends in cardiorespiratory fitness were also examined across area-level socioeconomic environment quartiles. The presence of a significant linear trend indicates a statistically significant increase or decrease across area-level socioeconomic environment quartiles. A significant quadratic trend indicates a statistically significant non-linear change (e.g., leveling off, change in direction). Significant linear and quadratic trends together indicate an overall linear increase/decrease; however, estimates also leveled off or began to increase/decrease across quartiles. All significance levels were set to $p<.05$. Analyses were conducted in SAS 9.4 using PROC GLIMMIX.

Results

Table 2.2 presents descriptive characteristics for the overall sample and by cardiorespiratory fitness Healthy Fitness Zone categories. The mean age for the overall sample was 12.4 years (±2.0) and approximately half of the overall sample was enrolled in 5th grade. Sex was distributed equally between male and female students. The sample was racially/ethnically diverse with 55.6% non-Hispanic white, 29.1% non-Hispanic black, 9.8% Hispanic, and 5.5% identifying as other race/ethnicity group including multiracial. Just over half of the overall sample had low family socioeconomic status. Finally, nearly 40% of the sample was overweight or obese and 52% achieved the Healthy Fitness Zone for cardiorespiratory fitness. Across sociodemographic categories, a greater proportion of students with the following characteristics achieved the Healthy Fitness Zone: 5th graders ($p<.0001$), males ($p<.0001$), non-Hispanic whites ($p<.0001$), high family socioeconomic status ($p<.0001$), normal weight ($p<.0001$), and attending school with more favorable area-level socioeconomic environments (Q1, affluent) ($p<.0001$).

Table 2.3 depicts the results from multilevel logistic regression analyses that examined the association between area-level socioeconomic environment and cardiorespiratory fitness level, before and after adjusting for individual-level sociodemographic characteristics. Area-level socioeconomic environment was significantly associated with odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness ($p<.05$). Specifically, the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness decreased by approximately 25-34% with increasing socioeconomic deprivation (Q2, Q3, Q4 compared to Q1), after controlling for covariates. Figure 2.1 depicts a significant linear and quadratic trend across area-level socioeconomic environment quartiles. While an overall decreasing trend was observed across area-level socioeconomic environment quartiles (linear trend: $p<.05$), a substantial decrease in the odds of achieving the Healthy Fitness Zone was observed from the first quartile to the second quartile followed by a leveling off of the effect across remaining quartiles (quadratic trend: $p<.01$). Further, the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness were significantly lower among females (OR = 0.43, 95% CI = 0.41, 0.45), low family socioeconomic status (OR = 0.59, 95% CI = 0.56, 0.62), overweight (OR = 0.37, 95% CI = 0.35, 0.39), obese (OR = 0.09, 95% CI = 0.08-0.10), and older students (8^{th} grade: OR = 0.46, 95% CI = 0.39, 0.55; high school: OR = 0.43; 95% CI = 0.34, 0.54) (Table 2.3).

Lastly, interaction terms were introduced into the adjusted model to determine whether the relationship between area-level socioeconomic environment and cardiorespiratory fitness varied by the student's grade level, sex, race/ethnicity, and family socioeconomic status. Significant interactions were found for sex ($p<.0001$), race/ethnicity ($p<.0001$), and grade level ($p<.0001$) (Table 2.4). The positive association between area-level socioeconomic environment and cardiorespiratory fitness held among males ($p<.05$); but not females ($p=0.24$). Figure 2.2 depicts significant quadratic trends across area-level socioeconomic environment quartiles for both sexes ($p<.01$), with a substantial decrease observed from the first quartile to the second quartile followed by a leveling off or slight change in direction across remaining quartiles. Across race/ethnicity subgroups, the association between area-level socioeconomic environment and cardiorespiratory fitness held for non-Hispanic white students ($p<.001$) and was marginally significant for non-Hispanic black students ($p=0.07$) and students from other race/ethnicity subgroups ($p=0.10$); but was not observed among Hispanic students ($p=0.93$) (Figure 2.3). By grade level, the influence of area-level socioeconomic environment was more pronounced among older students compared to younger students

(Figure 2.4). More specifically, the association between area-level socioeconomic environment and cardiorespiratory fitness was observed among high school students ($p<.05$), but not among 5th graders ($p=0.21$) and 8th graders ($p=0.81$). Among high school students, cardiorespiratory fitness decreased across area-level socioeconomic environment quartiles (linear trend: $p<.01$, quadratic trend: $p<.05$).

Discussion

The main finding of this study was a significant relationship between area-level socioeconomic environment and cardiorespiratory fitness levels. Specifically, the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness were lower among youth attending schools located in socioeconomically deprived areas compared to more affluent areas. The relationship between area-level socioeconomic environment and cardiorespiratory fitness, though attenuated, remained significant after controlling for individual-level characteristics. This suggests that area-level socioeconomic environment is independently associated with youth fitness levels. Further, a significant decreasing trend in cardiorespiratory fitness across area-level socioeconomic environment quartiles was observed.

To date, few studies have examined the relationship between area-level socioeconomic environment and cardiorespiratory fitness, especially among younger populations. The findings of previous studies have been mixed. Some studies have reported a relationship between socioeconomic deprivation and lower levels of cardiorespiratory fitness among young adults and school-age youth (12, 14). However, others have reported that cardiorespiratory fitness levels were significantly associated with school type (i.e., private vs. public) but not the socioeconomic environment (22). Notably, the results of this study support previous research that has reported an association between area-level socioeconomic environment and cardiorespiratory fitness among younger populations (12, 14). Further, the results of the present study suggest that area-level socioeconomic environment independently influences fitness levels among school-age youth.

Additionally, findings of this study demonstrated that the association between area-level socioeconomic environment and cardiorespiratory fitness varied significantly by sex, grade level, and race/ethnicity subgroups. The relationship between cardiorespiratory fitness and area-level socioeconomic environment was not observed in females, Hispanics, and younger age groups compared to their respective counterparts. Building from previous literature, there are several explanations that may describe these findings. With respect to sex, previous studies have reported that males may have increased independent mobility and thus may experience greater exposure to environmental factors compared to females (31–33). This may explain the stronger association observed among males compared to females. Similarly, previous evidence also suggests that the influence of environmental factors on health and health-related behaviors may increase during adolescence as youth become increasingly independent and gain more responsibility (34, 35). Hence, a stronger influence among older youth may be explained by increased and/or compounding exposure to environmental factors that influence cardiorespiratory fitness levels. Finally, existing literature has well-documented the ‘Hispanic paradox’, where individuals of Hispanic/Latino origin exhibit better cardiovascular health outcomes compared to non-Hispanic whites despite lower socioeconomic status and limited access to resources (36, 37). Some have postulated that this paradoxical relationship may be attributed to higher levels of social support and/or prevalence of nuclear families (36, 38). While it cannot be confirmed in the current study, these factors may explain the absence of a significant relationship between area-level socioeconomic environment and cardiorespiratory fitness among Hispanic youth. Notably, the findings of this study do not align with those of a previous study that examined a sample of young adults and reported no significant interactions between area-level socioeconomic environment and individual-level characteristics (14).

Our study contributes to the growing body of knowledge and addresses several gaps in the literature. This is one of the first studies to examine the association between area-level socioeconomic environment and cardiorespiratory fitness among youth using individual-level data. Unlike previous studies, we also explored the potential moderating role of demographic characteristics, including sex, grade level, race/ethnicity, and family socioeconomic status. However, some limitations should be noted. First, the study design was cross-sectional which does not allow for causality to be inferred. Second, cardiorespiratory fitness was determined using established field tests delivered and reported by staff from participating schools. While all staff received standard training prior to conducting FitnessGram tests, there was potentially variability in the measurement and reporting of cardiorespiratory fitness results. Finally, school census tract was used as a proxy since students' neighborhood of residence could not be determined. While not a perfect proxy for neighborhood socioeconomic environment, student enrollment in a given school is often determined by the neighborhood in which the family resides. In most instances, students are designated to attend the school in closest proximity to their home of residence. Thus, the immediate and surrounding environment of the school is likely representative of students' neighborhood environment (28, 29).

In summary, our findings detail the extent to which area-level socioeconomic environment is associated with cardiorespiratory fitness levels in a diverse sample of South Carolina youth. Unfortunately, nearly one out of every two youth in the study population had an inadequate level of cardiorespiratory fitness. Given the well-established relationship between cardiorespiratory fitness and cardiometabolic health, efforts to improve cardiorespiratory fitness levels among youth should be prioritized. Previous literature has identified several evidence-based strategies that have been shown to effectively improve youth fitness levels (39, 40). Accordingly, studies are needed to examine the potential moderating effect of the socioeconomic environment on the effectiveness of evidence-based strategies to improve youth fitness levels. Results of such studies could provide information that would help tailor evidence-based approaches for improving youth cardiorespiratory fitness levels in specific demographic subgroups.

Table 2.1. American Community Survey census tract variables selected to construct an area-level socioeconomic environment index by domain.

Domain	Variable
Education	Proportion of total population with less than a high school education
	Proportion of total population with a college degree (i.e., Associates, Bachelor, Graduate, Professional, Doctorate)
Occupation	Proportion of civilian noninstitutionalized males between 18 and 64 who are unemployed
	Proportion of civilian noninstitutionalized population between 18 and 64 who are unemployed
	Proportion female management occupations (i.e., white collar employment/management)
	Proportion male management occupations (i.e., white collar employment/management)
Housing Conditions	Proportion of household ownership (i.e., proportion of occupied housing units occupied by owner)
	Proportion of vacant households (i.e., proportion of housing units that are not occupied)
	Proportion of households with ≥ 1 person per room (i.e. crowding)
	Proportion of households with dependents that are headed by females (i.e., no male present)
	Median value of all owner-occupied households ($)
	Proportion of households on public assistance
Income and Poverty	Proportion of households with no car (includes owner and renter occupied households)
	Proportion of households with low income (i.e., < 200% of poverty level)
	Proportion households with income $150,000+
	Median household income
	Proportion of population living below the federal poverty level income
Racial Composition	Proportion of population non-Hispanic black or African-American
	Proportion of population Hispanic
Residential Stability	Proportion of residents age 65 years and older
	Proportion of persons living in same residence since 2005

Table 2.2. Student characteristics for the overall sample and by Healthy Fitness Zone for cardiorespiratory fitness.

		Cardiorespiratory Fitness (CRF)		
Student Characteristics [a]	**Total** (n=44,078)	Heathy Fitness Zone (n=22,729)	Needs Improvement / Health Risk (n=21,349)	p-value
Age (years)	12.4 (2.0)	12.3 (1.9)	12.5 (2.0)	<.0001
Grade				<.0001
5th grade	52.2%	54.2%	50.2%	
8th grade	25.7%	25.3%	26.1%	
High School	22.1%	20.5%	23.7%	
Sex				<.0001
Male	51.5%	58.8%	43.8%	
Female	48.5%	41.2%	56.2%	
Race/Ethnicity				<.0001
Non-Hispanic White	55.6%	59.3%	51.7%	
Non-Hispanic Black	29.1%	25.3%	33.1%	
Hispanic	9.8%	9.6%	10.0%	
Other	5.5%	5.8%	5.2%	
Family Socioeconomic Status				<.0001
Low	55.3%	47.8%	63.3%	
High	44.7%	52.2%	36.7%	
BMI	21.9 (5.5)	19.9 (3.7)	24.1 (6.3)	<.0001
Weight Status				<.0001
Normal Weight	60.3%	76.3%	43.3%	
Overweight	17.6%	15.1%	20.3%	
Obese	22.1%	8.7%	36.5%	
Estimated VO_2max	42.0 (6.3)	46.4 (5.5)	37.1 (2.5)	<.0001
CRF Field Test				<.0001
PACER	94.8%	93.0%	96.9%	
1-Mile Run/Walk Test	5.2%	7.0%	3.1%	
Area-Level Characteristics				
Socioeconomic Environment [b]				<.0001
Quartile 1 (Affluence)	29.2%	34.0%	24.2%	
Quartile 2	28.1%	27.7%	28.5%	
Quartile 3	24.1%	21.5%	26.9%	
Quartile 4 (Deprivation)	18.6%	16.7%	20.5%	

Notes: CRF, cardiorespiratory fitness.

[a] Presented as mean (standard deviation) unless denoted by percent, %; reported as percentage of column total.

[b] Index score calculated using data from the American Community Survey 5-year estimates from 2011-2015; quartiles based on distribution of index score across participating schools.

Table 2.3. Logistic regression models examining the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness by area-level socioeconomic environment.

	Unadjusted Model [a]	**Adjusted Model [b]**
Variables	OR (95% CI)	OR (95% CI)
Socioeconomic Environment		
Quartile 1 (Affluence)	1.0	1.0
Quartile 2	**0.65 (0.50, 0.83)**	**0.75 (0.56, 0.99)**
Quartile 3	**0.51 (0.40, 0.64)**	**0.66 (0.51, 0.87)**
Quartile 4 (Deprivation)	**0.52 (0.40, 0.67)**	**0.75 (0.55, 1.02)**
Sex		
Male		1.0
Female		**0.43 (0.41, 0.45)**
Race/Ethnicity		
NH White		1.0
NH Black		1.05 (0.99, 1.1)
Hispanic		**1.42 (1.30, 1.54)**
Other		**1.18 (1.07, 1.31)**
Family Socioeconomic Status		
High		1.0
Low		**0.59 (0.56, 0.62)**
Grade Level		
5th Grade		1.0
8th Grade		**0.46 (0.39, 0.55)**
High School		**0.43 (0.34, 0.54)**
Weight Status		
Normal		1.0
Overweight		**0.37 (0.35, 0.39)**
Obese		**0.09 (0.08, 0.10)**
Model Fit		
AIC	55,080	46,528
Socioeconomic Environment (p-value)	<.0001	<.05

Note: **Bold** typeface indicates significant odds ratios, OR = odds ratio; CI = confidence interval.

[a] Model accounts for nesting of students within schools.
[b] Model adjusted for CRF field test (PACER, Walk, 1-Mile Run) and accounts for students nested within schools and districts.

Table 2.4. Stratified logistic regression models examining the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness by area-level socioeconomic environment (quartiles) and individual-level covariates. [a]

	Socioeconomic Environment, Quartiles (Q)					
Variables	Q1	Q2	Q3	Q4	p-value	p-value for trend
Sex	OR	OR (95% CI)	OR (95% CI)	OR (95% CI)		
Female	1.0	0.68 (0.46, 1.01)	0.76 (0.52, 1.11)	0.71 (0.47, 1.07)	0.24	L: <.05 Q: <.01
Male	1.0	**0.62 (0.43, 0.88)**	**0.65 (0.46, 0.91)**	0.70 (0.48, 1.01)	**<.05**	L: .11 Q: <.01
Race/Ethnicity	OR	OR (95% CI)	OR (95% CI)	OR (95% CI)		
Non-Hispanic White	1.0	**0.52 (0.36, 0.74)**	**0.55 (0.39, 0.76)**	**0.63 (0.44, 0.91)**	**<.001**	L: <.01 Q: <.001
Non-Hispanic Black	1.0	**0.67 (0.46, 0.98)**	0.74 (0.52, 1.06)	**0.62 (0.43, 0.90)**	0.07	L: .06 Q: <.05
Hispanic	1.0	0.92 (0.60, 1.61)	1.05 (0.69, 1.61)	0.94 (0.60, 1.49)	0.93	L: .65 Q: .12
Other	1.0	0.75 (0.49, 1.15)	0.72 (0.48, 1.12)	**0.54 (0.33, 0.88)**	0.10	L: .07 Q: <.05
Grade Level	OR	OR (95% CI)	OR (95% CI)	OR (95% CI)		
5th Grade	1.0	0.89 (0.59, 1.33)	0.70 (0.47, 1.05)	1.05 (0.67, 1.64)	0.21	L: .15 Q: .69
8th Grade	1.0	0.76 0.39, 1.48)	0.83 (0.44, 1.59)	0.74 (0.39, 1.43)	0.81	L: 62 Q: <.01
High School	1.0	0.63 (0.35, 1.14)	0.59 (0.33, 1.06)	**0.43 (0.24, 0.79)**	0.05	L: **<.01** Q: <.05

Note: **Bold** typeface indicated significant odds ratios, OR = odds ratio; CI = confidence interval.

[a] Final adjusted model included significant interactions included gender * socioeconomic environment (p<.01), grade level * socioeconomic environment (p<.0001), race/ethnicity * socioeconomic environment (p<.01); AIC = 46,483; Odds ratios for interactions derived from stratified analyses from final adjusted model with significant interactions retained controlling for age, sex, race/ethnicity, poverty status, weight status, grade level, and cardiorespiratory fitness field test mode; and accounting for students nested within schools and district.

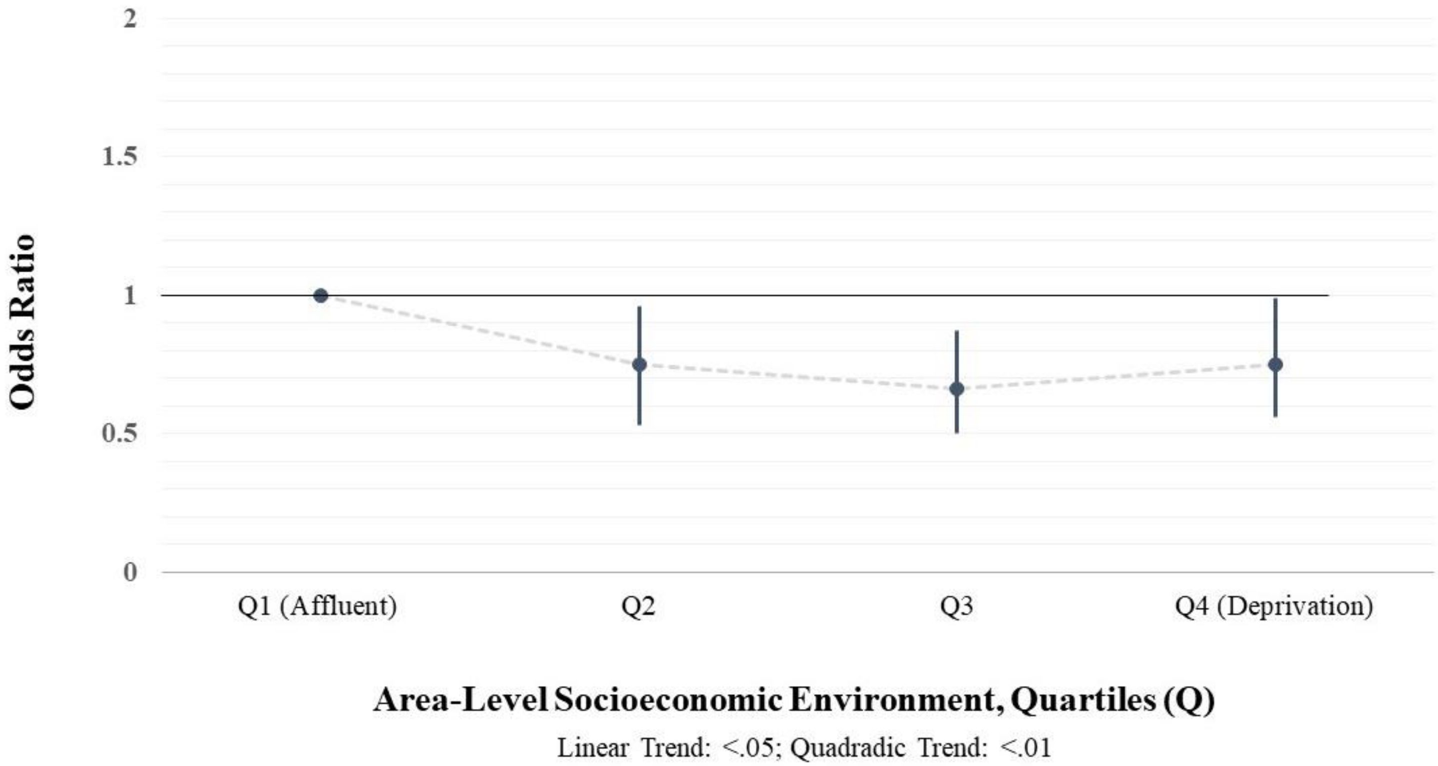

Figure 2.1. Adjusted odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness by area-level socioeconomic environment (quartiles).

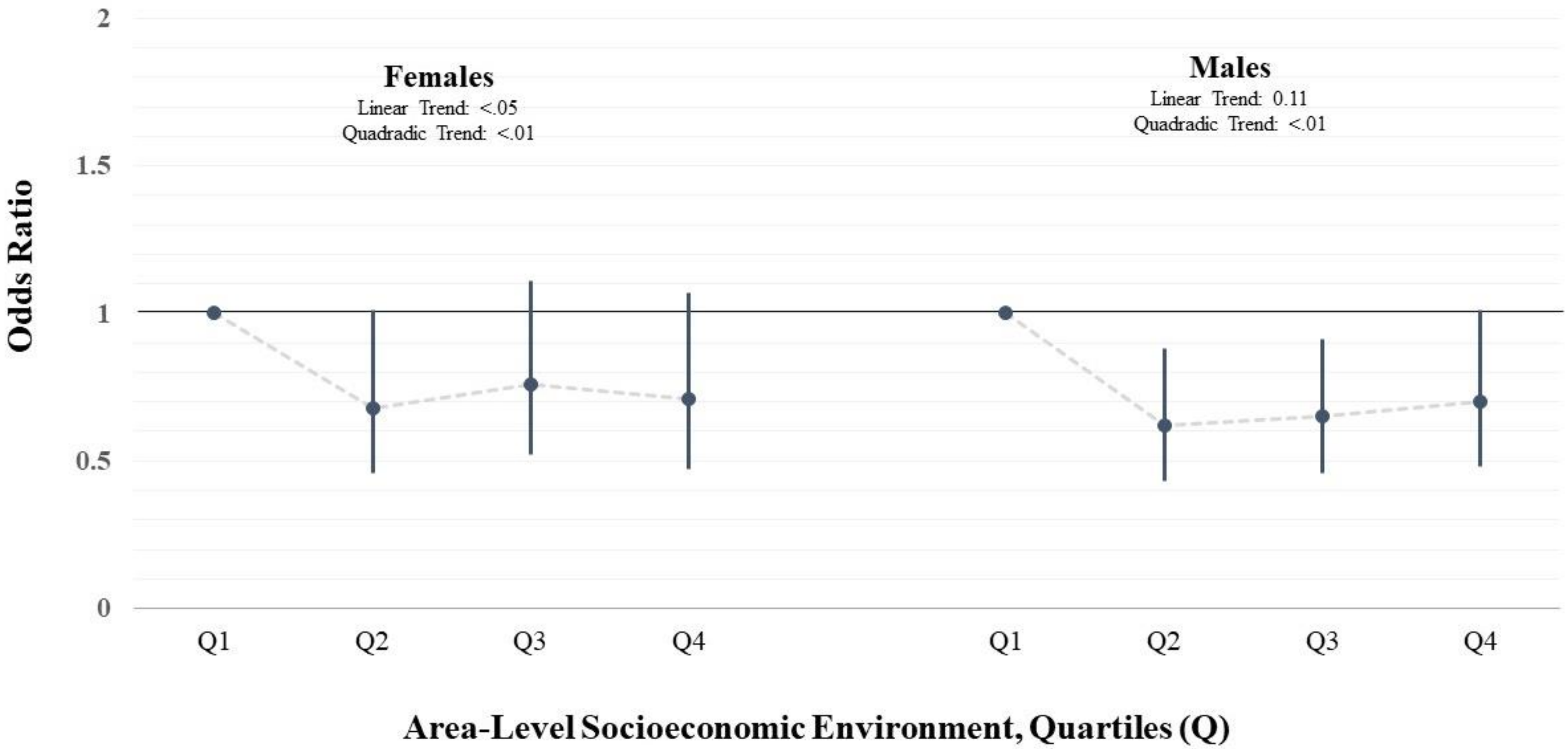

Figure 2.2. Adjusted odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness by area-level socioeconomic environment (quartiles) and sex.

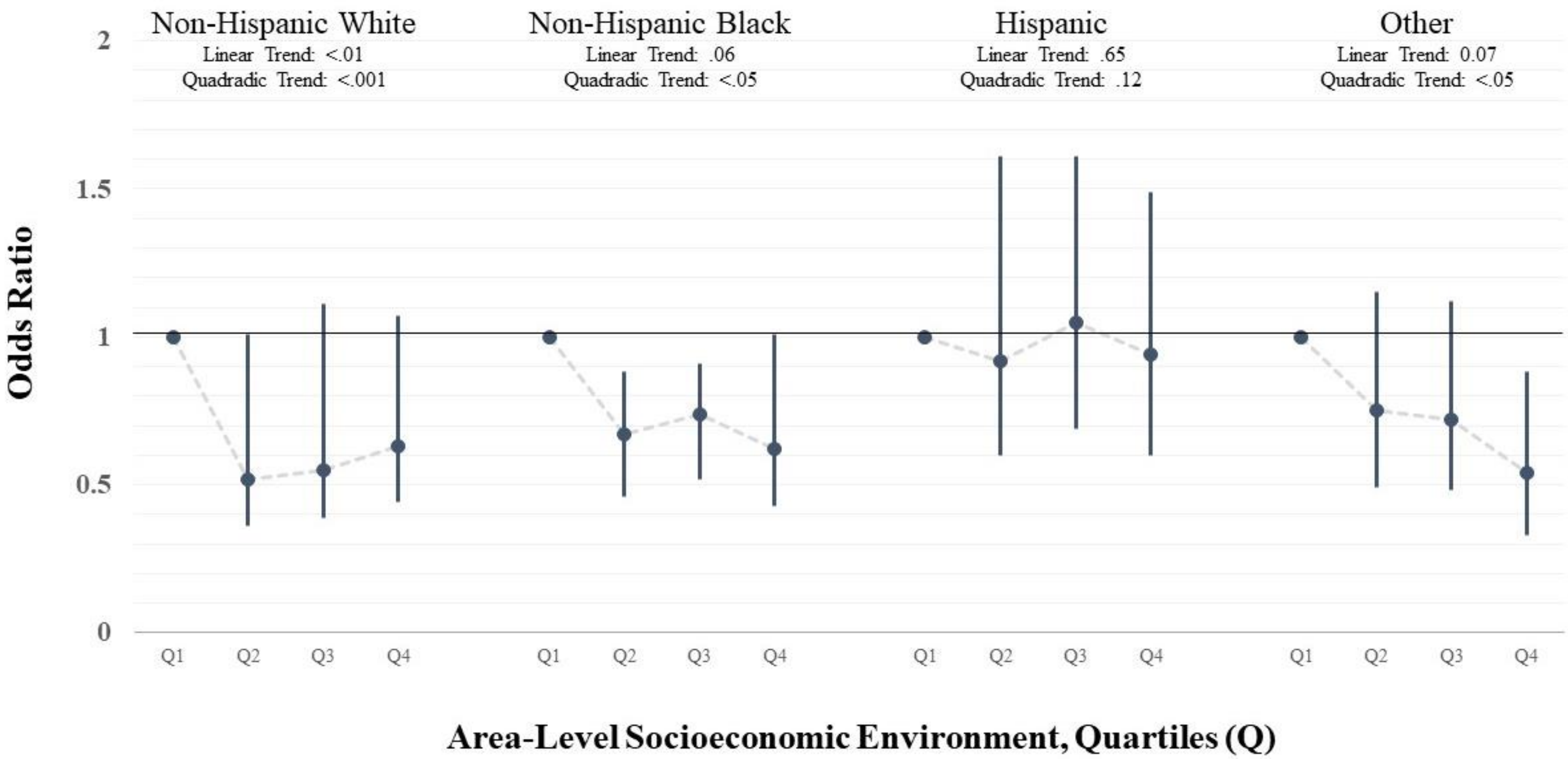

Figure 2.3. Adjusted odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness by area-level socioeconomic environment (quartiles) and race/ethnicity.

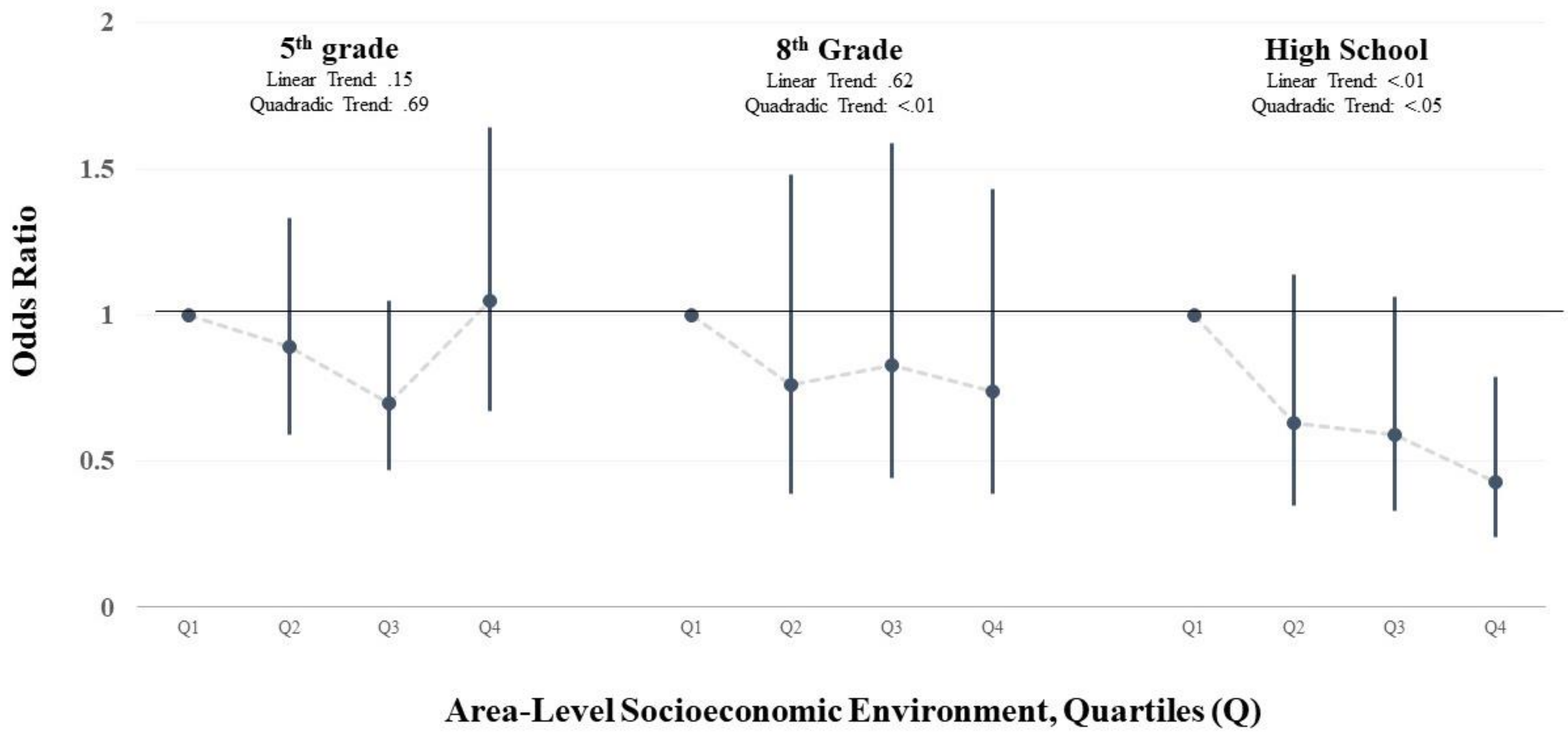

Figure 2.4. Adjusted odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness by area-level socioeconomic environment (quartiles) and grade.

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CHAPTER 3

MANUSCRIPT TWO: THE ASSOCIATION BETWEEN NEIGHBORHOOD SOCIOECONOMIC DEPRIVATION, CARDIORESPIRATORY FITNESS AND PHYSICAL ACTIVITY IN U.S. YOUTH[2]

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Abstract

Background. Cardiorespiratory fitness is an important marker of health and a strong predictor of cardiovascular disease and all-cause mortality in adults. Growing evidence suggests that the broader neighborhood socioeconomic environment is independently associated with cardiometabolic health. However, few studies have examined this relationship among younger populations. **Purpose:** The purpose of the study was to (1) investigate the association between neighborhood socioeconomic deprivation (SED) and cardiorespiratory fitness, controlling for potential individual-level covariates; and (2) determine the extent to which physical activity mediates this relationship in a nationally representative sample of U.S. youth. **Methods.** Data from 312 youth (12-15 years old) were obtained from the 2012 NHANES National Youth Fitness Survey. Cardiorespiratory fitness was measured using a standard submaximal treadmill test; and maximal oxygen consumption (i.e., VO_2max) was estimated. Physical activity was self-reported via a questionnaire designed to capture time spent in moderate-to-vigorous activity. Neighborhood SED was measured by a composite index score at the census tract of residence using American Community Survey data. Logistic regression analyses examined relationships between neighborhood SED, physical activity, and cardiorespiratory fitness, adjusting for individual-level covariates and the complex sampling design. **Results.** Neighborhood SED was not significantly associated with cardiorespiratory fitness or physical activity among youth in the study sample. **Conclusions.** While not significant, cardiorespiratory fitness levels were observed to decrease as neighborhood SED increased. Future research is needed to better understand

this relationship and to identify underlying mechanisms beyond fitness or physical activity that may drive the relationship between neighborhood SED and health.

Introduction

Strong evidence suggests that cardiorespiratory fitness is a powerful marker of health in youth and is associated with cardiometabolic health in adulthood (1–5). Unfortunately, cardiorespiratory fitness levels in youth have declined steadily over the past three decades (2, 6, 7). In the U.S., the most recent national surveillance data indicate that the percentage of youth (12-15 years old) with adequate cardiorespiratory fitness levels has decreased by approximately 10 percent since 2000 (8). As of 2012, nearly 3 in 5 U.S. youth were estimated to have inadequate cardiorespiratory fitness levels (8). Much is known about the individual-level characteristics (e.g., genetics, age, sex) and behaviors (e.g., physical activity) that influence cardiorespiratory fitness in youth (3, 9). However, little is known about factors at the community- or neighborhood-level that may influence youth fitness levels.

A growing body of literature has consistently reported a positive association between neighborhood socioeconomic deprivation (SED) and numerous health outcomes in adults, including cardiovascular disease, mortality, and related cardiometabolic risk factors (10–18). More specifically, existing evidence suggests that individuals residing in neighborhoods with unfavorable or deprived socioeconomic environments are more likely to have poor cardiovascular health (19). This clustering of adverse health outcomes within various geographic scopes suggest that ‘place’, or where one lives, plays a significant role in influencing health (20, 21). However, most of the literature to date has focused on the influence of neighborhood SED on cardiovascular disease and related risk factors in adult populations (16, 19).

While considerable evidence suggests that cardiovascular disease originates in childhood and adolescence (22), limited research has examined the relationship between neighborhood SED and risk factors for cardiovascular disease in younger populations. Specifically, the independent influence of neighborhood SED on cardiorespiratory fitness among youth remains relatively unexplored. Given the well-documented effect of physical activity on cardiorespiratory fitness (3, 23, 24), it is also of interest to examine the extent to which physical activity, a modifiable behavior, mediates the potential relationship between neighborhood SED and cardiorespiratory fitness in youth. As such, the primary purpose of this study was to investigate the association between neighborhood SED and cardiorespiratory fitness in a nationally representative sample of U.S. youth. A secondary aim was to determine the extent to which physical activity mediates the hypothesized relationship between neighborhood SED and cardiorespiratory fitness.

Methods

Data Source & Study Design. Data were obtained from the 2012 National Health and Nutrition Examination Survey (NHANES) National Youth Fitness Survey (NNYFS). The NNFYS was conducted by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics (NCHS) in conjunction with 2012

NHANES (25). It employed a cross-sectional study design and used a complex, stratified, multistage probably cluster sampling design Data were collected from 492 youth (12 to 15 years old) via a household interview and a physical examination. The analytic sample included 312 participants with complete data for variables of interest. Participants with missing data (27 missing demographic information; 36 cardiorespiratory fitness; 29 physical activity; and 88 neighborhood SED) were excluded from the analysis; no significant differences were observed across the two groups for any variables of interest. Each participant and a parent/guardian provided informed written consent prior to participation in the study. All protocols were reviewed and approved by the NCHS Review Board. Additional details regarding the study protocols, sampling, data collection, and measurement are available in the NNYFS manual (25).

Cardiorespiratory Fitness. Cardiorespiratory fitness was measured using a standard submaximal treadmill test. Trained staff determined the treadmill test protocol using participant's age, sex, body mass index (BMI), and self-reported physical activity level. Heart rate was measured during each exercise stage of the treadmill test and used to estimate maximal oxygen consumption (i.e., VO_2max). Using age- and sex-specific thresholds established by the FITNESSGRAM protocol, estimated VO_2max was then categorized into one of two fitness levels: 'Healthy Fitness Zone' or 'Needs Improvement'(25).

Neighborhood Socioeconomic Deprivation (SED). Neighborhood was defined as a participant's census tract of residence. A composite index score at the census tract level was created using data from the American Community Survey (ACS) 5-year estimates

2011-2015. To calculate the index, 21 census tract variables across six domains were obtained for all census tracts in the contiguous U.S. (Table 3.1). Principal component analysis with varimax rotation was used to examine the data structure (26, 27). The first common factor explained 38.9% of the variance and included nine variables with greater factor loading on the first common factor: proportion with less than a high school education, proportion with a college degree, proportion female management occupations, proportion male management occupations, proportion of households with low income, median household income, proportion living below the federal poverty level, proportion of female headed households, median value of all owner-occupied households. Principal component analysis was rerun with these selected variables. Final variable loading coefficients were used to compute a weighted and standardized index (mean = 0; standard deviation = 1) with higher scores indicating more unfavorable neighborhood socioeconomic environments (i.e., deprivation). Continuous expression of the index score was not permitted by the NCHS due to risk of participant identification. The neighborhood SED index score was expressed categorically for all analyses: Low (≤30th percentile), Moderate (31st to 70th percentile), High (>70th percentile).

Physical Activity. Physical activity was self-reported via a questionnaire designed to assess time spent in moderate and vigorous physical activity across three settings (i.e., recreation, work, and transportation). Using the NNYFS suggested metabolic equivalent (MET) scores, physical activity time estimates were converted into MET-minutes per week (28) (Table 3.2). Physical activity was expressed as average daily MET-minutes and calculated by summing the estimated MET-minutes per week across the three settings then dividing by seven.

Covariates. Individual-level sociodemographic variables included age (in years), sex (male, female), race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, and other), family socioeconomic status (measured as family income-to-poverty ratio), and weight status (underweight/normal weight: <85th percentile; overweight: 85th percentile to <95th percentile; obese: ≥95th percentile). Additional details regarding demographic variables are available in the NNYFS protocols (25).

Statistical Analyses. The NCHS's Research Data Center (RDC) created the analytic dataset by merging the researcher's measure of neighborhood SED with publicly available NNYFS data using restricted geographic information (i.e., census tract corresponding to participant's residence). Descriptive statistics and bivariate associations between predictor variables and cardiorespiratory fitness were examined for the unweighted sample. Logistic regression was employed to examine the relationships among neighborhood SED, physical activity, and cardiorespiratory fitness. First, the unadjusted association between neighborhood SED and cardiorespiratory fitness was examined. Next, demographic covariates were added to the model separately then simultaneously. Lastly, the influence of physical activity on the relationship between cardiorespiratory fitness and neighborhood SED was examined, controlling for demographic covariates. Sample weights were used in all models to account for the complex sampling design and to allow for inferences to be made at the population level. Model fit and assumptions were assessed for all models. Alpha level of 0.05 was used to determine statistical significance for all analyses. Analyses were conducted in NCHS's ANDRE platform using SAS procedures PROC SURVEYLOGISTIC.

Results

Table 3.3 presents descriptive statistics for the total unweighted sample and for two subsamples based on achieving the Healthy Fitness Zone for cardiorespiratory fitness. The mean age was 13.6 years. Overall, the distribution of male and female participants was approximately equal, and the racial/ethnicity distribution was diverse. Nearly 40% of participants were classified as overweight or obese. The average physical activity was 618.3 MET minutes per day and 44% achieved the Healthy Fitness Zone for cardiorespiratory fitness. Approximately 41% of participants resided in a census tract with high neighborhood SED. Across Healthy Fitness Zone categories for cardiorespiratory fitness, a greater proportion of male and normal weight participants achieved the Healthy Fitness Zone ($p<.0001$). Additionally, participants achieving the Healthy Fitness Zone category had significantly lower BMIs and reported higher physical activity levels ($p<.0001$).

Table 3.4 presents results from the logistic regression analyses examining the relationship between neighborhood SED, physical activity, and Healthy Fitness Zone for cardiorespiratory fitness, after adjusting for demographic covariates. First, the relationship between the neighborhood SED and cardiorespiratory fitness was examined controlling for individual covariates. Then, physical activity was added to the model (Figure 3.1). In both models, neighborhood SED was not significantly associated with odds of achieving Healthy Fitness Zone for cardiorespiratory fitness ($p=.35$ and $p=.34$, respectively). However, physical activity was significantly associated with odds of achieving Healthy Fitness Zone for cardiorespiratory fitness ($p<.001$). Additionally, the odds of achieving Healthy Fitness Zone for cardiorespiratory fitness were significantly lower among participants that were obese ($p<.001$) and those with lower family socioeconomic status ($p<.05$).

Linear regression analyses using a continuous expression of cardiorespiratory fitness were also examined. Findings were similar to those of the logistic regression analyses (not presented). Formal mediation tests were not performed since the measure of neighborhood SED was not significantly associated with the outcome or potential mediating variable.

Discussion

The primary finding of this study was that neighborhood SED was not significantly associated with cardiorespiratory fitness in a nationally representative sample of 12-15-year-old U.S. youth. We had hypothesized that neighborhood SED would be negatively associated with cardiorespiratory fitness and that physical activity would mediate the relationship. Several factors may explain the absence of significant findings in the present study. First, the small sample size and NHANES study design may have reduced our ability to detect a significant relationship due to inadequate statistical power. While the NNYFS provided a nationally representative sample, the analytic sample was reduced by approximately 36% due to missing data for variables of interest in this study. The use of sample weights may have further reduced statistical power by introducing variability into the model due to larger standard errors. Second, cardiorespiratory fitness continues to develop throughout early adolescence (29). Despite the strong study methodology and carefully standardized measurement of cardiorespiratory fitness, there was likely considerable variability in cardiorespiratory fitness due to developmental differences across the study sample (i.e., maturity status). Finally, the influence of neighborhood SED on cardiorespiratory fitness may not yet be measurable during this developmental life stage due to insufficient length of exposure (e.g., lag time to measurable health outcomes). Together, these factors may have resulted in less precise findings and increased the likelihood of null results.

While this study did not detect a significant relationship between neighborhood SED and cardiorespiratory fitness, the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness decreased with increasing neighborhood SED. This trend was not statistically significant. However, the observed pattern aligns with existing literature that has reported poorer health outcomes and higher prevalence of several cardiovascular disease risk factors among individuals residing in socioeconomically deprived neighborhoods (16, 19, 30–34). Our findings also mimic the associations observed between SED and cardiorespiratory fitness across the few studies that have examined this relationship. One study examined this relationship among younger adults (25-42 years old) and reported low levels of cardiorespiratory fitness among those residing in socioeconomically disadvantage neighborhoods (16). Similarly, another study reported that school SED was significantly association with cardiorespiratory fitness and accounted for 26.6% and 20.8% of the variability in fitness levels among boys and girls, respectively (31).

Additionally, our results demonstrated that self-reported moderate-to-vigorous physical activity was positively associated with cardiorespiratory fitness among youth after controlling for individual-level characteristics. These findings are consistent with the well-established relationship between physical activity and cardiorespiratory fitness (3, 9, 35, 36). Further, our findings align with previous studies that have utilized 2012 NNYFS data to examine this relationship (37, 38). One study reported that higher physical activity levels (i.e., meeting physical activity guidelines and MET minutes/week) were associated with increased odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness (37). Another study reported a significant association between physical activity and cardiorespiratory fitness among females; however, the relationship was not observed among males (38). While a significant relationship between physical activity and cardiorespiratory fitness was observed in the present study, neither physical activity or cardiorespiratory fitness were found to be significantly associated with neighborhood SED. A potential explanation for this finding may be that physical activity exerts a stronger and more proximal influence on cardiorespiratory fitness compared to neighborhood SED. Due to these null associations, physical activity was not examined as a potential mediator of the relationship between neighborhood SED and cardiorespiratory fitness.

Given the discrepancy between our findings and existing literature, additional research is needed to better understand how neighborhood SED influences cardiometabolic health across the lifespan. The current paper provides a foundation for future studies to build upon to expand our understanding of this complex relationship. Future research should replicate the current study in larger and diver populations and also explore the direct and indirect pathways that may help to explain how and when the neighborhood SED 'gets under the skin' to influence health (16, 39, 40).

This study includes several strengths that help to address gaps in existing literature. To the authors' knowledge, this is the first study to examine the relationship between neighborhood SED and cardiorespiratory fitness in a nationally representative sample of U.S. youth. Unlike previous studies, we also set out to examine the potential mediating role of physical activity and controlled for individual-level sociodemographic characteristics known to influence cardiorespiratory fitness. Despite these strengths, some limitations should be noted. First, data use restrictions imposed by the RDC resulted in a reduced sample size due to missing data and reduced statistical power due to limitations in variable expression. Second, the cross-sectional study design does not allow for the potential causal relationship between neighborhood SED and cardiorespiratory fitness to be examined. Third, physical activity was self-reported, which could result in over- or under-estimation of activity levels. With respect to neighborhood SED, the use of residential census tracts is not a perfect measure of neighborhood. However, the area in proximity to an individual's home has consistently been used to assess characteristics of the neighborhood environment (19, 41). Finally, due to restricted access of geographic information, neighborhood SED had to be examined as a categorical variable in all analyses. This limitation likely influenced the results and may explain, in part, the non-significant trends observed in the present study.

Conclusions/Implications. Despite the findings of the current study, the persistent focus on poor cardiovascular health in socioeconomically disadvantaged neighborhoods suggests that local environmental factors play a significant role in influencing health. However, the pathways explaining how neighborhood SED potentially influences cardiometabolic health are not well understood. To intervene effectively on perilously low cardiorespiratory fitness levels among U.S. youth, a deeper understanding of the multi-level factors influencing health are needed, especially at the environmental level. Future research should aim to 1) expand our understanding of the relationship between neighborhood SED and cardiovascular health; 2) identify the emergence of this relationship during the life course; and 3) examine the underlying mechanisms that help to explain how SED influences health. A comprehensive understanding of this relationship will help to identify key leverage points for public health intervention and can inform the development of effective upstream environmental and policy strategies to promote health in youth and beyond.

Table 3.1. American Community Survey census tract variables (n=21) selected to construct a neighborhood socioeconomic deprivation index by domain.

Domain	Variable
Education	Proportion of total population with less than a high school education
	Proportion of total population with a college degree (i.e., Associates, Bachelor, Graduate, Professional, Doctorate)
Occupation	Proportion of civilian noninstitutionalized males between 18 and 64 who are unemployed
	Proportion of civilian noninstitutionalized population between 18 and 64 who are unemployed
	Proportion female management occupations (i.e., white collar employment/management)
	Proportion male management occupations (i.e., white collar employment/management)
Housing Conditions	Proportion of household ownership (i.e., proportion of occupied housing units occupied by owner)
	Proportion of vacant households (i.e., proportion of housing units that are not occupied)
	Proportion of households with ≥ 1 person per room (i.e. crowding)
	Proportion of households with dependents that are headed by females (i.e., no male present)
	Median value of all owner-occupied households ($)
	Proportion of households on public assistance
Income and Poverty	Proportion of households with no car (includes owner and renter occupied households)
	Proportion of households with low income (i.e., < 200% of poverty level)
	Proportion households with income $150,000+
	Median household income
	Proportion of population living below the federal poverty level income
Racial Composition	Proportion of population non-Hispanic black or African-American
	Proportion of population Hispanic
Residential Stability	Proportion of residents age 65 years and older
	Proportion of persons living in same residence since 2005

Table 3.2. NNYFS Suggested MET Scores for self-reported time spent in moderate and vigorous physical activity across three settings.

Setting	Physical Activity Intensity	Suggested MET Score
Recreation	Moderate	4.0
	Vigorous	8.0
Work	Moderate	4.0
	Vigorous	8.0
Transportation	Walking or Biking	4.0

Table 3.3. Unweighted youth (12-15 years old) characteristics for the overall sample and by Healthy Fitness Zone for Cardiorespiratory Fitness. [a]

		Cardiorespiratory Fitness (CRF)		
	Total	**Healthy Fitness Zone**	**Needs Improvement**	
Variable	n=312	n=138	n=174	p-value [b]
Age (mean, sd)	13.6 (1.1)	13.6 (1.1)	13.6 (1.1)	0.57
Sex (%)				
Male	160 (51.3%)	85 (61.6%)	75 (43.1%)	0.001
Female	152 (48.7%)	53 (38.4%)	99 (56.9%)	
Race/Ethnicity (n, %)				
Non-Hispanic White	136 (44.6%)	62 (44.9%)	74 (42.5%)	0.73
Non-Hispanic Black	74 (23.7%)	31 (22.5%)	43 (24.7%)	
Hispanic	79 (25.3%)	37 (26.8%)	42 (24.1%)	
Other	23 (7.4%)	8 (5.8%)	15 (8.6%)	
Family Socioeconomic Status (mean, sd)	2.3 (1.6)	2.2 (1.6)	2.5 (1.6)	0.15
BMI (mean, sd)	22.7 (5.3)	21.0 (4.0)	24.0 (5.8)	<.0001
Weight Status (n, %)				
Normal Weight	190 (60.9%)	107 (77.5%)	83 (47.7%)	<.0001
Overweight	58 (18.6%)	19 (13.8%)	39 (22.4%)	
Obese	64 (20.5%)	12 (8.7%)	52 (29.9%)	
Physical Activity METS minutes per day (mean, sd)	618.3 (560.7)	778.4 (640.9)	491.4 (450.8)	<.0001
Estimated VO_2max (mean, sd)	41.3 (9.9)	49.7 (8.9)	34.7 (4.0)	<.0001
Neighborhood Socioeconomic Deprivation (n, %)				
Low	65 (20.8%)	31 (22.5%)	34 (19.5%)	0.81
Moderate	119 (38.1%)	51 (37.0%)	68 (39.1%)	
High	128 (41.1%)	56 (40.6%)	72 (41.4%)	

[a] descriptive statistics for unweighted sample reported as mean, standard deviation [mean, (sd)] or frequency and percentage [n (%)]; sd = standard deviation

[b] chi-square test or t-test used to determine significant differences across Healthy Fitness Zone categories

Table 3.4. Logistic regression models examining the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness by neighborhood socioeconomic deprivation (SED) and physical activity; 2012 NNYFS.

Variable	**Neighborhood SED Model** [a]	**Physical Activity Model** [b]
	OR (95% CI)	OR (95% CI)
Neighborhood SED		
Low	1.0 (ref)	1.0 (ref)
Moderate	0.71 (0.24, 2.11)	0.73 (0.27, 2.00)
High	0.57 (0.25, 1.28)	0.54 (0.23, 1.29)
Physical Activity		**1.001 (1.001, 1.002)**
Age	1.03 (0.87, 1.22)	0.99 (0.81, 1.20)
Sex (Female)	**0.36 (0.20, 0.66)**	**0.44 (0.24, 0.79)**
Race/Ethnicity		
Non-Hispanic White	1.0 (ref)	1.0 (ref)
Non-Hispanic Black	0.62 (0.25, 1.51)	0.63 (0.25, 1.57)
Hispanic	0.87 (0.32, 2.37)	1.06 (0.38, 2.98)
Other	0.57 (0.21, 1.55)	0.57 (0.23, 1.42)
Weight Status		
Normal Weight	1.0 (ref)	1.0 (ref)
Overweight	**0.34 (0.14, 0.82)**	0.41 (0.15, 1.08)
Obese	**0.11 (0.05, 0.25)**	**0.13 (0.05, 0.31)**
Family Socioeconomic Status	**0.77 (0.63, 0.95)**	**0.80 (0.66, 0.96)**
Model Fit Parameters		
AIC	12597637	12192857
-2 Log Likelihood	12597615	12192833
R-Square	0.176	0.207

Notes: **Bold** typeface indicated significant odds ratios; SED = socioeconomic deprivation; OR = odds ratio; CI = confidence interval

[a] Model examines the relationship between Healthy Fitness Zone for cardiorespiratory fitness and neighborhood SED controlling for age, sex, race/ethnicity, family socioeconomic status, and weight status.

[b] Model examines the relationship between Healthy Fitness Zone for cardiorespiratory fitness, neighborhood SED, and physical activity controlling for age, sex, race/ethnicity, family socioeconomic status, and weight status.

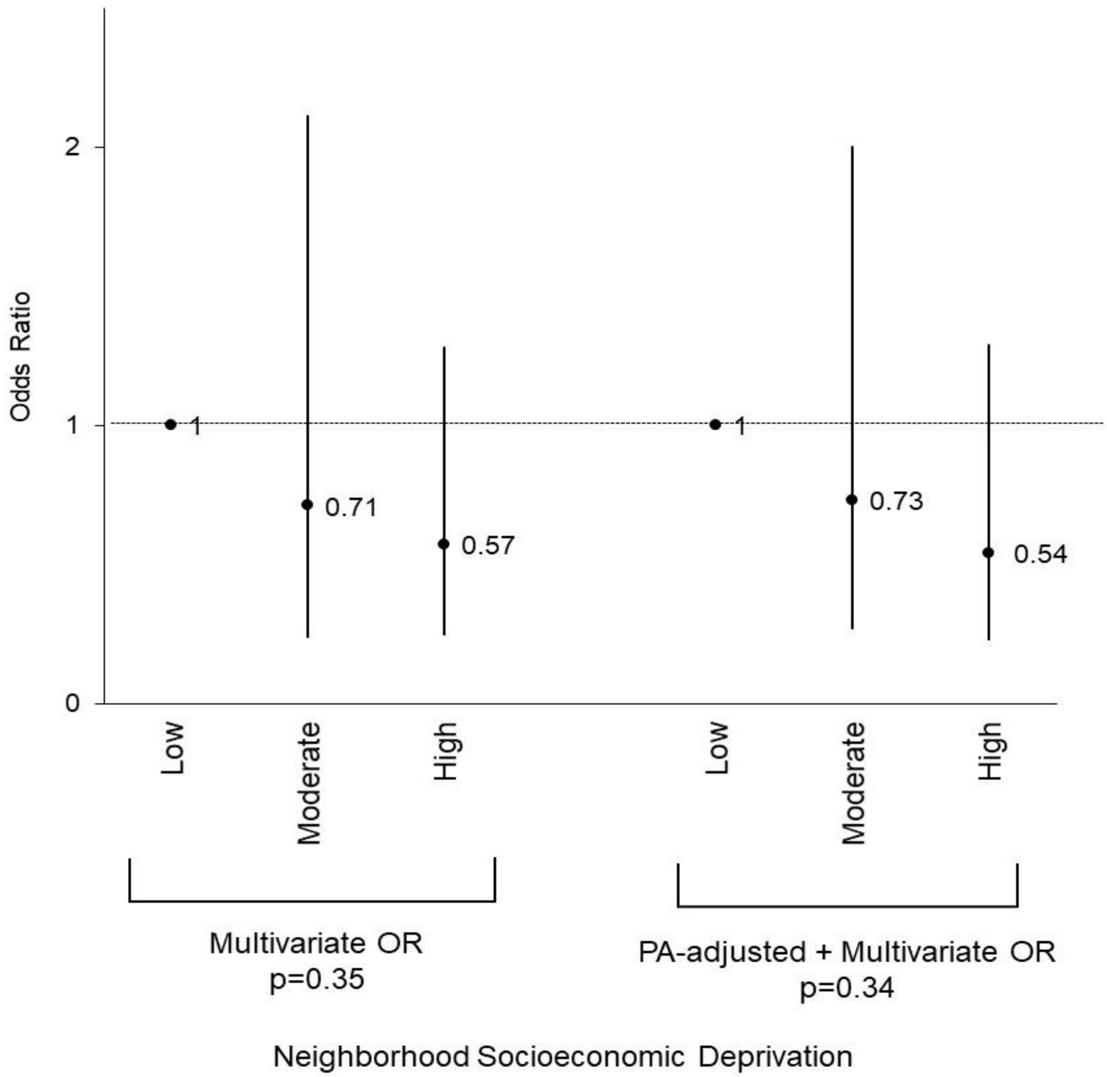

Figure 3.1. Odds ratios (ORs) and 95% confidence intervals for achieving Healthy Fitness Zone for cardiorespiratory fitness by neighborhood socioeconomic deprivation in youth; 2012 NNYFS.[a]

Notes: OR = odds ratio; PA = physical activity

[a] Models adjusted for age, sex, race/ethnicity, family socioeconomic status, and weight status.

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CHAPTER 4

MANUSCRIPT THREE: ASSOCIATIONS BETWEEN NEIGHBORHOOD SOCIOECONOMIC DEPRIVATION, PHYSICAL ACTIVITY FACILITIES, AND PHYSICAL ACTIVITY IN YOUTH DURING THE TRANSITION FROM CHILDHOOD TO ADOLESCENCE[3]

[3] Clennin, MN, Colabianchi, N, Kaczynski, A, Sui, X, Pate, RR. To be submitted to *Health and Place.*

Abstract

Purpose: To describe the longitudinal association of neighborhood socioeconomic deprivation (SED) with physical activity in youth during the transition from childhood to adolescence, and to determine if access to physical activity facilities moderates this relationship. **Principal Results:** Decreases in PA varied by degree of neighborhood SED with youth residing in the most deprived neighborhoods experiencing the greatest declines in physical activity. Access to supportive physical activity facilities did not moderate this relationship. **Conclusion:** Future research studies are needed to better understand how neighborhood SED influences youth physical activity over time.

Introduction

Physical activity declines precipitously during the transition from childhood (6-11 years old) to early adolescence (12-15 years old) (1). Among children and adolescents, previous research has identified numerous individual-level determinants and correlates of physical activity (2–6). However, evidence suggests that upstream environmental factors become increasingly influential during adolescence as youth gain independence and responsibility (7–10). In response, research examining the influence of socioeconomic and built environmental factors on physical activity behaviors has increased dramatically in the past two decades (7, 8). Two areas of increased interest in physical activity research among youth is the neighborhood socioeconomic and built environment (Alvarado, 2016a; Sallis et al., 2006).

To date, few studies have examined the influence of neighborhood socioeconomic deprivation (SED) on physical activity levels among youth. Across existing studies, findings have been inconsistent. Some research has reported a significant association between indicators of neighborhood SED and physical activity (12–15). In general, these studies observed lower physical activity levels among youth residing in less favorable or deprived neighborhoods (16). However, other studies have reported no significant association (17). Several limitations such as cross-sectional study designs and considerable variability in measurement of physical activity and neighborhood SED may contribute to the inconsistencies observed.

With respect to the built environment, previous research has extensively explored its relationship with youth physical activity levels (18–21). Across recent systematic review and meta analyses, findings have been mixed and vary by type of built environment feature examined, measurement, study population, and methodology employed. In general, however, reviews have concluded that sufficient evidence exists to support a relationship between youth physical activity levels and several features of the built environment. For example, the availability of supportive physical activity facilities and built environment design features have been identified as characteristics of the neighborhood environment associated with youth physical activity levels (18, 19, 21). Notably, however, existing evidence regarding the relationship between physical activity facilities and youth activity levels has been inconsistent with some reviews supporting an association while others report null findings (18–21).

While sufficient evidence supports a relationship between several features of built environment and physical activity, little is known about how neighborhood SED interacts with physical activity facilities to influence among youth activity levels (16, 17, 22–24).

Failure to account for this potential interaction may confound previous research findings and impede public health efforts to create supportive physical activity environments (16, 22, 23, 25). Hence, the present study aims to fill gaps in the literature by addressing the following objectives: (1) describe the longitudinal association of neighborhood SED with physical activity in youth during the transition from childhood to adolescence; and (2) determine if the presence of supportive physical activity facilities moderates this relationship.

Methods

Data for this study were obtained from the Transitions and Activity Changes in Kids (TRACK) study. TRACK was a multi-level, longitudinal study designed to examine the factors that influence changes in physical activity as youth transition from elementary to middle school (26, 27). Briefly, 1,090 5th graders (501 boys, 579 girls) from 21 elementary schools in two urban South Carolina school districts were enrolled in the study in 2010. Students were followed into middle school. At each measurement period, participants completed a questionnaire, had anthropometric measurements taken, and received an accelerometer to measure physical activity. Written parental consent and child assent were obtained. The analytic sample for the current study included 660 youth with complete data in grades 5 (baseline) and 7 (follow-up). Participants with missing data were excluded from the analytic sample. This study was approved by the University of South Carolina's Institutional Review Board.

Physical Activity. Physical activity was measured using accelerometry (ActiGraph GT1M and GT3X models, Pensacola, FL); only the vertical axis of the GT3X model was used in order to be comparable to the GT1M model (28–31). Each participant was instructed to wear an accelerometer on their right hip during waking hours for seven consecutive days, except while bathing, swimming, or sleeping. Data were collected and stored in 60-second epochs. All periods of non-wear time, defined as ≥ 60 minutes of consecutive zero activity counts, were set to missing (32). Data for Sundays were excluded from the analytic dataset due to limited data availability (i.e., ~ 73% of total possible records were from Monday to Saturday). To be included in the analytic sample, at least two days with eight hours of accelerometer wear time each day were required. Missing values were then imputed using a sex-specific multiple imputation method via PROC MI in SAS (Version 9.3; SAS Institute, Inc., Cary, NC) (Freedson et al., 2005). Age-specific thresholds were applied to accelerometer count data to determine activity levels (Freedson et al., 2005). Physical activity was defined as ≥ 100 activity counts per minute and included light, moderate, and vigorous intensity levels (32, 33). Physical activity was expressed as average daily minutes of physical activity per hour of wear time.

Neighborhood Socioeconomic Deprivation (SED). Neighborhood SED was expressed as a composite index score at the census tract level using data from the American Community Survey (ACS) 5-year estimates for 2006-2010 (Lian, 2016; ACS). To calculate the SED index, 21 census tract variables across 6 domains were obtained for all South Carolina and North Carolina census tracts where participants lived (Table 4.1). Principal component common factor analysis with varimax rotation was used to examine the data structure of the census tract variables. The first common factor accounted for the largest proportion of the total variance (35.9%). Twelve variables with significantly greater factor loading in the first common factor were selected to build the socioeconomic deprivation index, including the percentage of population with less than a high school education, the percentage of working class, the percentage of civilian labor force unemployed, the percentage of households in poverty, the percentage of female-headed households with dependent children, the percentage of households with family income less than $30,000 per year, the percentage of households with public assistance, the percentage of households with no car, the percentage of households with no phone, income disparity, the percentage of population below the federal poverty line, and the percentage of non-Hispanic African American population. There was high internal consistency for these twelve selected variables (Cronbach's alpha=0.93). Next, selected variables were standardized and weighted based on their corresponding factor score coefficient from the principal component analysis. Finally, a composite index score was constructed by summing these values. Neighborhood SED was expressed as a continuous index score with higher values indicating greater neighborhood deprivation. For ease of interpretation, neighborhood SED index was categorized into quartiles based on distribution of index scores.

Neighborhood Physical Activity Facilities. The Physical Activity Resource Assessment (PARA) was used to examine physical activity facilities that have been shown to influence physical activity. The PARA assessed features (e.g. baseball field), amenities (e.g. drinking fountains), and incivilities (e.g., graffiti) of facilities that provide physical activity opportunities and resources (34). Within each community, data were collected between the students' 5th and 6th grade school years. Trained data collectors identified all operational facilities that offered physical activity opportunities in the study communities (i.e., churches, commercial facilities, trails, parks, and schools). For each operational facility, a PARA was completed and a facility-specific score accounting for the presence of features, amenities, and incivilities was calculated. Then, a student-specific PARA index score was created for each student by summing the scores of all facilities within a 0.75-mile network buffer surrounding the participant's home address using GIS software (ArcGIS 10.1) (35). Higher student-specific PARA index scores suggest greater availability of quality physical activity facilities, while lower scores represent less availability of physical activity facilities. Using the median value, student-specific PARA scores were also categorized into two groups (supportive vs. non-supportive).

Student Characteristics. Participants reported their age, gender, and race/ethnicity via a student survey. Race and ethnicity groups were collapsed into four categories: non-Hispanic white, non-Hispanic black, Hispanic, and other (including multi-racial). As part of the parent survey, a parent or guardian reported their highest level of education. For the present analyses, parent education was categorized into two groups (≤ high school education; > high school education). Height and weight were measured at each measurement period by trained data collectors. Standing height was measured to the nearest 0.1 cm using a portable stadiometer (SECA, Hamburg Germany). Weight was measured to the nearest 0.1 kg using a portable electronic scale (SECA, Hamburg, Germany). Weight status was determined using age- and sex-specific body mass index

(BMI) percentiles from 2000 CDC growth charts: underweight/normal weight (<85^{th} percentile), overweight (85^{th} percentile to <95^{th} percentile), and obese (≥95^{th} percentile) (36).

Statistical Analyses. Means and standard deviations were calculated for participant age, BMI, physical activity, and environment variables; and frequencies and percentages were calculated for gender, race/ethnicity, parent education, and weight status by quartiles of neighborhood SED and for the total sample at baseline. Significant differences across neighborhood SED quartiles were examined for each variable via the appropriate statistical test (i.e., ANOVA and chi-square test, respectively). Then, bivariate associations between predictor variables, covariates, and physical activity were examined.

To examine the relationship between neighborhood SED and physical activity over time and the potential moderating role of supportive physical activity facilities, a series of multilevel linear regression models were generated. First, the association between physical activity and neighborhood SED was examined. Next, two-way interactions between time, neighborhood SED, and supportiveness of PA were introduced into the model separately and then simultaneously. Finally, a three-way interaction term between time, neighborhood SED, and supportiveness of physical activity facilities was added to the model. All models were adjusted for individual-level covariates and accounted for clustering of participants in census tracts and school districts. Model fit was assessed using maximum likelihood estimation methods and Akaike's Information Criterion (AIC). An alpha level less than 0.05 was used to denote statistical significance for two-sided statistical tests. For ease of interpretation, continuous expressions of neighborhood SED index and student-specific PARA scores were categorized and used to produce model-derived least square means. All analyses were conducted in SAS using the PROC MIXED procedure.

Results

Table 4.2 depicts the participant and neighborhood characteristics for the overall sample and by neighborhood SED quartiles. At baseline, the mean age was 10.6 (± 0.05) years and the gender distribution was approximately equal (45.6% male vs. 54.4% female). With respect to race and ethnicity, the sample was diverse with 38.3% non-Hispanic white, 36.1% non-Hispanic black, 9.2% Hispanic, and 16.4% other racial/ethnicities including multiracial. Nearly 60% of parents/guardians reported attending some college or obtaining a higher education degree. The average BMI was 21.2 (± 5.0) kg/m^2 and just over half of the sample was classified in the normal weight status category. The weight status for the remainder of the sample included 0.5% underweight, 17.0% overweight, and 30.9% obese. Finally, the average minutes of physical activity per hour controlled for wear time was 28.4 (± 4.5) (Table 4.2).

At baseline, some significant differences across neighborhood SED quartiles were present (Table 4.2). Age differed across neighborhood SED quartiles, with older participants observed in the first and last quartiles, representing the most affluent and most deprived neighborhoods ($p<.01$). Participants that identified as non-Hispanic white and/or had parents with greater than a high school education were significantly more likely to reside in more affluent neighborhoods, while participants that identified as non-

Hispanic black and/or with less educated parents were significantly more likely to reside in more deprived neighborhoods ($p<0.05$). Additionally, the distribution of BMI and weight status was significantly different across neighborhood SED quartiles ($p<.05$). Specifically, BMI and the proportion of youth classified as obese increased as neighborhood SED increased ($p<.05$). At baseline, physical activity minutes per hour did not vary significantly across neighborhood SED quartiles ($p=0.06$). Finally, participants residing in deprived neighborhoods has significantly higher PARA index scores, indicating greater availability of quality physical activity facilities ($p<.001$).

Table 4.3 presents results from regression models that assessed the longitudinal relationship between physical activity, neighborhood SED, and supportiveness of physical activity facilities, after adjusting for individual-level demographic characteristics and clustering of youth in neighborhoods and school districts. Over time, changes in physical activity were found to vary significantly by degree of neighborhood SED (Model 2; $p<.05$). Additionally, a significant interaction between neighborhood SED and the supportiveness of physical activity facilities was observed (Model 4; $p<.05$). Lastly, a 3-way interaction was introduced to the model to determine if supportiveness of physical activity facilities moderated the relationship between neighborhood SED and changes in physical activity. The interaction between time, neighborhood SED index, and supportiveness of physical activity facilities was not significant ($p=0.09$) indicating that supportiveness of physical activity facilities does not significantly moderate the relationship between neighborhood SED and changes in physical activity from 5^{th} to 7^{th} grade.

Adjusted Least Squared Means. To visually depict and interpret significant interactions, adjusted least square means are presented. Regarding the interaction between neighborhood SED and time (Model 2), changes in physical activity from 5th grade to 7th grade varied significantly by neighborhood SED quartile. Over time, physical activity declined significantly among all youth regardless of the degree of neighborhood socioeconomic deprivation. However, youth residing in neighborhoods with higher SED (Q4) experienced the largest decline in physical activity. Specifically, 5th graders residing in neighborhoods with higher SED (Q4) had the highest activity levels and were significantly more active than youth residing in the least deprived neighborhoods (Q1). By 7th grade, there was no significant difference in activity level across neighborhood SED quartiles. (Table 4.4, Figure 4.1).

The three-way interaction between time, neighborhood SED index, and presence of supportive physical activity facilities was not significant (p=0.09), despite the fact that two two-way interactions (time * neighborhood SED; neighborhood SED * presence of supportive physical activity facilities) were significant (Model 5). For ease of interpretation, model-derived estimates were generated for the three-way interaction to better depict findings. In 5th grade, youth residing in affluent neighborhoods (Q1) with access to supportive physical activity facilities were significantly less active than youth residing in neighborhood characterized as 1) low SED (Q1) and non-supportive physical activity facilities; 2) low-moderate SED (Q2) and supportive physical activity facilities; and 3) high SED (Q4) and supportive physical activity facilities. Over time, physical activity declined significantly among all youth regardless of the degree of neighborhood

SED and/or presence of supportive physical activity facilities. By 7^{th} grade, no significant differences in activity levels remained. Again, youth residing in neighborhoods with high SED (Q4) were observed to have the largest decline in physical activity regardless of access to supportive physical activity facilities (Table 4.5; Figure 4.2).

Discussion

The key finding of the present study was a significant association between neighborhood SED and changes physical activity among a large cohort of South Carolina youth. Our findings demonstrate that declines in physical activity from 5^{th} grade to 7^{th} grade vary by the degree of neighborhood SED. Specifically, youth residing in the most deprived neighborhoods had the greatest declines in physical activity, going from the most to least active during the transition from 5^{th} to 7^{th} grade. In 5^{th} grade, youth residing in more deprived neighborhoods were more active than youth residing in more affluent neighborhoods. By 7^{th} grade, however, differences in physical activity levels dissipated. To the best of our knowledge, this is the first study to document the longitudinal relationship between neighborhood SED and changes in objectively-measured physical activity among youth.

The potential moderating role of physical activity facilities on the relationship between neighborhood SED and changes in physical activity was also examined. Our findings indicate that the relationship between neighborhood SED and physical activity as youth transition from childhood to adolescence was not different based on the presence of supportive physical activity facilities. While previous literature supports a relationship between features of the built environment and youth physical activity levels (19, 21, 37, 38), the findings of the present study highlight the importance of the broader socioeconomic environment on physical activity levels over time. Further, these findings build on previous research and address gaps in the scientific literature by examining the influence of neighborhood SED on changes in physical activity and the potential mediating role of the physical activity facilities on this relationship.

Across previous cross-sectional studies, findings are inconsistent, with approximately half having reported a significant relationship between indicators of neighborhood SED and physical activity (12–17, 22–25, 39). Notably, only two studies have used objective measures of physical activity (14, 22). The findings from the current study are consistent with these cross-sectional studies, which found that neighborhood SED was not associated with objectively-measured physical activity (Table 4.3 Model 1). Several studies have also examined the influence of features of the built environment in conjunction with indicators of neighborhood SED on physical activity among youth (16, 17, 22–25, 39). In general, the findings from these studies have varied. One study reported no significant association between physical inactivity and neighborhood SED and/or the presence of physical activity-related facilities (17). In another study, De Meester et al. (2012) reported that the relationship between neighborhood walkability and objectively-measured physical activity varied by degree of neighborhood SED. Specifically, the association only held for adolescents living in deprived neighborhoods. Their findings suggest that youth residing in neighborhoods characterized by deprived socioeconomic environments may be more likely to engage in physical activity when supportive built environments are present (22). However, the results from this study did not support their conclusion.

Taken together, our results demonstrate that neighborhood SED may exert a stronger influence on changes in physical activity among youth than the presence of supportive physical activity facilities. While the underlying mechanisms explaining how neighborhood SED might influence youth physical activity levels are complex and multi-faceted, our findings indicate these factors are associated with changes in physical activity among youth. Notably, the present study observed that youth residing in more deprived neighborhoods experienced the greatest declines in physical activity despite having greater availability, on average, to supportive physical activity resources. Given our findings, it is imperative that public health professionals consider the contextual factors in the neighborhood environment that may influence the effectiveness of built environment interventions designed to improve activity levels among youth.

A key strength of this study is the longitudinal study design. In addition to being the first longitudinal study to examine the relationship between neighborhood SED and physical activity, we also examined the potential moderating role of physical activity facilities on this relationship. While this study addresses several gaps in the literature, some limitations should be noted. First, accelerometers are limited in their ability to capture some types of activities (i.e., non-weight bearing and water-based activities) and do not provide contextual information (i.e. type and location) about physical activity behavior. With respect to neighborhood SED, the specific characteristics used were limited to those that were measured in existing data sources. As such, it is possible that some influential predictors were not included in the analyses. Further, our measure of the built environment was limited to the presence of physical activity facilities. Several other built environment characteristics such as walkability and pedestrian infrastructure could also be relevant. Finally, the use of residential census tracts is not a perfect measure of neighborhood; however, it has been used consistently in previous studies (37, 40) and spatial analytic techniques were considered to help determine if information from neighboring census tracts improved model fit (not reported).

In summary, inequalities in neighborhood environments are identified as a driver of health disparities and pose a serious public health challenge. Given the increased prevalence of physical inactivity, it is of great relevance to understand the influence of neighborhood SED on physical activity across the lifespan. While the present study provides a strong foundation for future research to build upon, additional studies are needed to replicate these findings and further expand the body of knowledge. Specifically, rigorous research that aims to understand how neighborhood SED influences physical activity over time is needed. A comprehensive understanding of this relationship will better inform the development and implementation of effective environmental and policy strategies to improve physical activity among youth, especially those from socioeconomically-disadvantaged backgrounds.

Table 4.1. Census tract variables used to construct neighborhood socioeconomic deprivation index score; Data Source: American Community Survey 5-year estimates, 2008-2012.

Domain	**ACS Variables**
Education	% of total population with less than a high school education
Occupation	% of working class
	% of civilian labor force unemployed
Housing Conditions	% of household ownership
	% of vacant households
	% of households with more than 1 person per room
	% of households in poverty
	% of female headed households with dependent children
	% of households with income <$30,000
	% of households with public assistance
	% of households with no car
	% of households with no phone
	% of households with incomplete plumbing
	% of households with no kitchen
Income and Poverty	Income disparity
	% of population below the federal poverty line
Racial Composition	% of population non-Hispanic African American
	% of population Hispanic
Residential Stability	% of residents aged ≥ 65 years
	% of persons living in same residence for ≥ 5 years
	% of foreign born

Table 4.2. Baseline sample characteristics for TRACK participants (n=660) and neighborhoods (n=42) by neighborhood socioeconomic deprivation (quartiles).

		Neighborhood Socioeconomic Deprivation, Quartiles[b]				
Child Characteristics[a]	**Total Sample** (n=660)	**Q1** (n=152)	**Q2** (n=276)	**Q3** (n=156)	**Q4** (n=76)	**p-value**[c]
Age (years)	10.6 (0.5)	10.7 (0.5)	10.5 (0.5)	10.5 (0.6)	10.6 (0.6)	<0.01
Gender						
Male	45.6%	44.7%	45.3%	51.3%	36.8%	0.22
Female	54.4%	55.3%	54.7%	48.7%	63.2%	
Race/Ethnicity						
Non-Hispanic White	38.3%	55.9%	42.4%	24.4%	17.0%	<0.0001
Non-Hispanic Black	36.1%	18.4%	25.7%	54.5%	71.1%	
Hispanic	9.2%	7.9%	11.2%	9.0%	5.3%	
Other (including multi-racial/ethnic)	16.4%	17.8%	20.7%	12.1%	6.6%	
Parent Education						
≤ High School Education	42.9%	33.6%	43.1%	46.8%	52.6%	<0.05
> High School Education	57.1%	66.4%	56.9%	53.2%	47.4%	
Body Mass Index	21.2 (5.0)	20.1 (4.4)	20.9 (4.5)	22.0 (5.5)	23.2 (6.4)	<0.0001
Weight Status						
Underweight	0.5%	0.7%	0.7%	0.0%	0.0%	<0.05
Normal Weight	51.6%	61.8%	51.4%	47.4%	40.8%	
Overweight	17.0%	17.8%	18.1%	14.1%	17.1%	
Obese	30.9%	19.7%	29.8%	38.5%	42.1%	
Physical Activity (Minutes/Hour)	28.4 (4.5)	28.1 (4.3)	28.0 (4.3)	28.1 (4.9)	29.6 (4.8)	0.06
Neighborhood Characteristics						
Physical Activity Facilities[e]	3.1 (6.0)	2.1 (4.1)	3.0 (6.2)	2.3 (3.7)	7.2 (9.5)	<0.0001
Supportive	58.8%	69.7%	60.9%	62.2%	22.4%	<0.0001
Non-Supportive	41.2%	30.3%	39.1%	37.8%	77.6%	

[a] Presented as mean (standard deviation) unless otherwise denoted by percent, %; reported as percentage of column total.

[b] Neighborhood socioeconomic deprivation categories determine using quartiles based on distribution of neighborhood socioeconomic deprivation index score across South Carolina census tracts.
[c] ANOVA and Chi-Square used to test for baseline differences between neighborhood socioeconomic deprivation categories for continuous and categorical variables, respectively.
[d] Index score calculated using data from the American Community Survey 5-year estimates from 2006-2010. Neighborhood defined as census tract corresponding to participant’s home address.
[e] Physical Activity Resources Assessment (PARA) used to assess supportiveness of physical activity facilities; an index score was calculated for each participant by summing PARA scores for all physical activity facilities located within a 0.75-mile network buffer around participant’s home address; median split applied to determine categories.

Table 4.3. Relationship between physical activity (minutes per hour), neighborhood socioeconomic deprivation (SED) and elements of the built environment (PARA) over time among TRACK participants. [a]

Variable	Model 1.	Model 2.	Model 3.	Model 4.	Model 4.	Model 5.
	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)
Time	-4.51 *** (0.54)	-4.68 *** (0.54)	-4.45 *** (0.55)	-4.52 *** (0.54)	-4.69 *** (0.54)	-4.61 *** (0.54)
SED	0.21 (0.23)	0.50 † (0.28)	0.21 (0.24)	0.05 † (0.27)	0.79 * (0.31)	0.66 † (0.32)
PARA	-0.005 (0.02)	-0.005 (0.02)	0.005 (0.03)	0.002 (0.03)	0.01 (0.03)	0.001 (0.03)
Time * SED		-0.59 * (0.27)			-0.58 * (0.27)	-0.31 (0.32)
Time * PARA			-0.02 (0.03)		-0.01 (0.03)	-0.0002 (0.03)
SED * PARA				-0.06 * (0.03)	-0.06 * (0.27)	-0.03 * (0.32)
Time * SED * PARA						-0.06 † (0.04)
Model Fit Parameters						
-2 Log Likelihood	7506.9	7502.3	7506.4	7502.0	7494.4	7494.6
AIC	7536.9	7534.3	7538.4	7534.0	7531.4	7532.6

[a] All models adjust for age, gender, race/ethnicity, parent education, weight status, and community; and account for clustering of measurements within participants within census tracts.

Notes: SED, neighborhood socioeconomic deprivation; PARA, Physical Activity Resource Assessment; † $p<0.1$, *$p<0.05$; **$p<0.01$; ***$p<0.001$

Table 4.4. Adjusted least squared means of physical activity (minutes/hour) among TRACK participants by grade level and neighborhood socioeconomic deprivation. [a]

	Neighborhood Socioeconomic Deprivation, Quartiles (Q)			
Time	**Q1 (Affluence)**	**Q2**	**Q3**	**Q4 (Deprivation)**
5th Grade	27.25 (0.49)[b]	27.61 (0.39)	27.63 (0.45)	28.72 (0.62)[b]
7th Grade	22.94 (0.47)	23.30 (0.36)	22.92 (0.46)	22.79 (0.61)
Change in Physical Activity	-4.31 (0.56)*	-4.31 (0.52) *	-4.71 (0.57)*	-5.94 (0.69)*

[a] Model adjusted for age, gender, race/ethnicity, parent education, weight status, and school district, and accounted for measurements clustered within participants clustered with in census tract; Model derived estimates presented as adjusted least squared means and standard error for interaction between time and neighborhood socioeconomic deprivation; Superscript letters indicate significant differences between adjusted least squared means, $p<0.05$

[b] Significant difference in physical activity (minutes/hour) between youth residing in quartile 1 vs quartile 4 in 5th grade

* Significant decline in physical activity from 5th to 7th grade; $p <0.0001$

Table 4.5. Adjusted least squared means of physical activity (minutes/hour) among TRACK participants by grade level, neighborhood socioeconomic deprivation (quartiles), and supportiveness of built environment.

Physical Activity Facilities	**Neighborhood Socioeconomic Deprivation (SED), Quartiles**			
	Q1 (Affluence)	**Q2**	**Q3**	**Q4 (Deprivation)**
Non-Supportive				
5th grade	27.81 (0.54)[a]	27.70 (0.44)	27.88 (0.54)	28.42 (1.11)
7th grade*	22.90 (0.52)	23.28 (0.42)	23.27 (0.53)	21.79 (1.11)
Supportive				
5th grade	25.99 (0.72)[a,b,c]	27.52 (0.51)[b]	27.33 (0.62)	28.83 (0.68)[c]
7th grade*	23.03 (0.70)	23.35 (0.49)	22.41 (0.64)	23.08 (0.67)

Notes: Model adjusted for age, gender, race/ethnicity, parent education, weight status, and school district; and accounted for measurements clustered within participants clustered with in census tracts; Model derived estimates presented as adjusted least squared means and standard error for interaction between time, neighborhood socioeconomic deprivation, and supportiveness of physical activity facilities; $p<0.1$; Superscript letters indicate significant differences between adjusted least squared means, $p<0.05$; * Significant decline in TPA from 5th to 7th grade was observed in each SED * PA Environment category

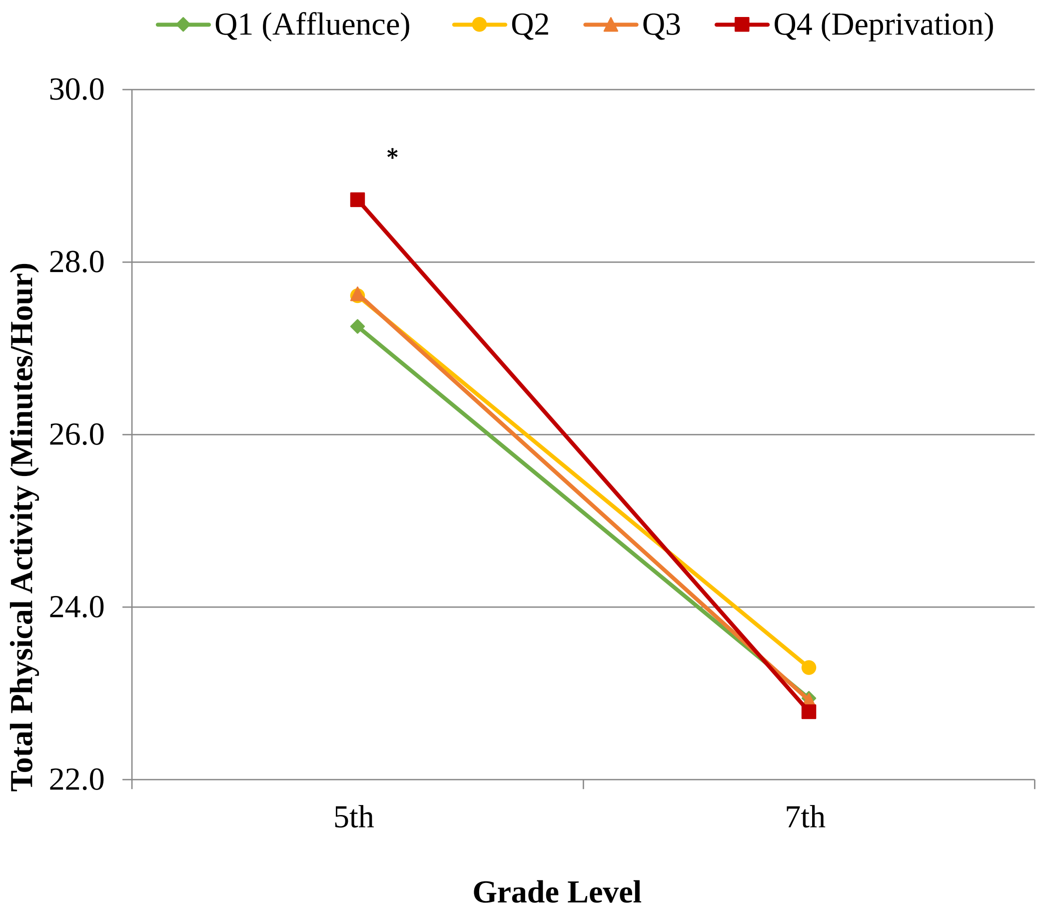
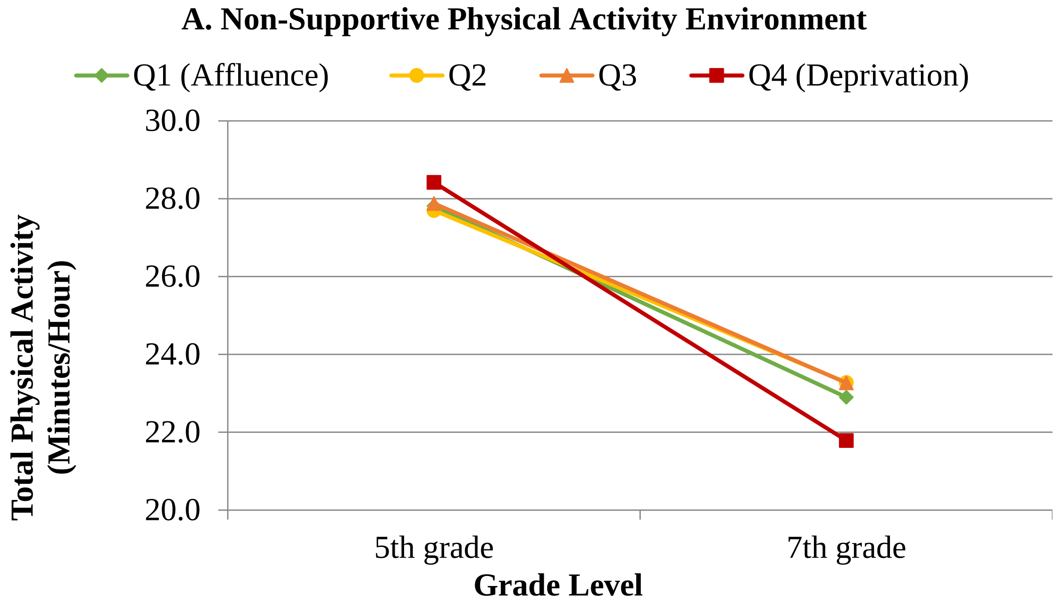


Figure 4.1. Adjusted least squared means of physical activity (minutes/hour) among TRACK participants by grade level and neighborhood socioeconomic deprivation (SED).



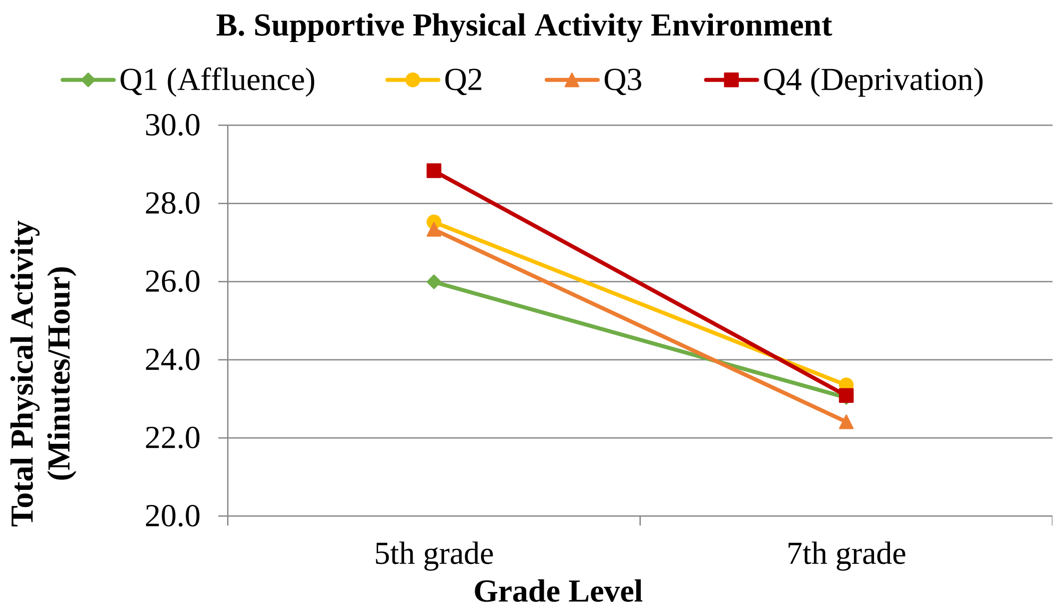


Figure 4.2. Adjusted least squared means of physical activity (minutes/hour) among TRACK participants by grade level, neighborhood socioeconomic deprivation (quartiles), and supportiveness of physical activity resources.

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CHAPTER 5

OVERALL DISCUSSION

Significance

A majority of youth in the U.S. do not have adequate levels of cardiorespiratory fitness and do not meet physical activity guidelines. Based on the most recent surveillance data, only 42% of U.S. youth (12-15 years old) had an adequate level of cardiorespiratory fitness, as determined by age- and sex-specific thresholds (1, 2). Further, the percentage of youth with adequate cardiorespiratory fitness has decreased significantly from 52% in 1999-2000 to 42% in 2012; an average decline of -0.78% per year. Additionally, only six to eight percent of youth achieve the recommended level of health-enhancing physical activity according to the most recent surveillance data (3). As such, it is of great relevance to identify the factors associated with physical inactivity and poor cardiorespiratory fitness in youth and to understand these complex relationships.

While previous research has identified several individual-level characteristics associated with youth cardiorespiratory fitness and physical activity levels, environmental-level factors have been increasingly acknowledged for their influence on health-related outcomes and behaviors. Recently, inequalities in socioeconomic environments have been identified as a driver of health disparities and may pose a serious challenge to public health efforts to improve population health. Research has consistently reported poorer health outcomes among individuals residing in areas of concentrated deprivation (i.e. poor socioeconomic environments). Such disparities in health do not occur at random but are thought to result from differential exposure to environmental factors that either promote or deter health-related behaviors (4–6). The persistent concentration of poor health outcomes in disadvantaged areas suggests that environmental factors, such as the neighborhood socioeconomic environment, play a significant role in influencing health (7).

To date, little is known regarding the influence of neighborhood socioeconomic environment on health-related outcomes and behaviors during youth. This lack of knowledge regarding the influence of the neighborhood socioeconomic environment on cardiorespiratory fitness and physical activity may limit our ability to develop effective approaches to improve fitness and activity levels among youth. Research that aims to understand how neighborhood socioeconomic environment influences disease risk factors and associated health behaviors in youth is needed to address the gaps in the literature. Hence, this dissertation is significant because it provides important information that helps to understand the complex relationships between neighborhood socioeconomic environment, cardiorespiratory fitness, and physical activity in youth. This research addressed gaps in the literature and represents a logical and important step in understanding the influence of the socioeconomic environment on health across the lifespan.

Purpose

The overarching purpose of this dissertation was to determine if characteristics of neighborhood socioeconomic environment are associated with cardiorespiratory fitness and physical activity in diverse samples of youth. The purpose of the first study was to examine the relationship between cardiorespiratory fitness and area-level socioeconomic environment in a diverse sample of school-aged youth; and to determine the extent to which sex, grade level, race/ethnicity, and family socioeconomic status moderated this relationship. The purpose of the second study was to investigate the association between neighborhood socioeconomic deprivation and cardiorespiratory fitness; and to determine the extent to which physical activity mediated this relationship in a nationally representative sample of U.S. youth. Finally, the purpose of the third study was to describe the longitudinal association of neighborhood socioeconomic environment with physical activity in youth during the transition from childhood to adolescence, and to determine if access to physical activity facilities moderated this relationship.

Design & Methods

The three studies included in this dissertation employed two study designs. The first and second study used a cross-sectional study design to examine the association between cardiorespiratory fitness and the socioeconomic environment. With respect to the first study, data from the South Carolina FitnessGram project was used to address the research aim. The outcome variable, cardiorespiratory fitness, was estimated using field tests administered by trained school staff and established protocols. The primary exposure variable, socioeconomic environment was expressed as a composite index score at the census tract level using data from the American Community Survey. Finally, student-level characteristics were reported by school administrators and/or the South Carolina Department of Education. In the second study, data were obtained from the 2012 NHANES National Youth Fitness Survey. Cardiorespiratory fitness, the outcome variable, was measured using a standard submaximal treadmill test; and maximal oxygen consumption (i.e., VO_2max) was estimated using established protocols. Physical activity, the potential mediating variable, was self-reported via a questionnaire designed to capture time spent in moderate-to-vigorous activity. Again, neighborhood socioeconomic environment was measured by a composite index score at the census tract of residence using data from the American Community Survey. Both studies employed multilevel logistic regression analyses to examine relationship between cardiorespiratory fitness and the socioeconomic environment, controlling for individual-level characteristics and sampling designs.

Lastly, the third study used data from the TRACK study, a prospective observational study that examined changes in physical activity among a cohort of youth from two South Carolina communities. The outcome variable of interest was total physical activity, which included light, moderate, and vigorous intensity activity levels. It was measured objectively via accelerometry and expressed as average daily minutes of physical activity per hour of wear time. Similar to the first two studies, neighborhood socioeconomic environment was expressed as a composite index score at the census tract level using data from the American Community Survey. To assess the supportiveness of the built environment for physical activity, the Physical Activity Resource Assessment (PARA) tool was used to examine features and amenities of community facilities/resources that have been shown to influence physical activity. This third study employed multilevel linear regression analyses to account for the hierarchical structure of the data.

Major Findings

Overall, the findings of this dissertation support the hypothesis that the neighborhood socioeconomic environment is related to cardiorespiratory fitness and physical activity in youth. In study one, cardiorespiratory fitness was positively associated with area-level socioeconomic environment among school-age youth in South Carolina. Specifically, the odds of achieving the Healthy Fitness Zone for cardiorespiratory fitness decreased by approximately 25-34% with increasing deprivation of the area-level socioeconomic environment, after controlling for covariates. The association between cardiorespiratory fitness and area-level socioeconomic environment also varied significantly by sex, grade level, and race/ethnicity subgroups.

Notably, the findings of study two were inconsistent with those of study one and previous studies. Results of the second study suggest that the neighborhood socioeconomic environment is not significantly associated with cardiorespiratory fitness or physical activity among youth in the study sample. However, cardiorespiratory fitness levels were observed to decrease as deprivation of the neighborhood socioeconomic environment increased. It is likely that lack of statistical power due to small sample size and use of sample weights may have limited our ability to detect a significant relationship between the neighborhood socioeconomic environment and cardiorespiratory fitness.

In the third study, changes in physical activity from 5^{th} grade to 7^{th} grade were significantly associated with neighborhood socioeconomic environment. Over time, decreases in physical activity were observed to vary by neighborhood socioeconomic environment. Specifically, youth residing in the most deprived neighborhoods experienced the greatest declines in physical activity. Access to supportive physical activity facilities did not moderate this relationship.

Taken together, the findings of this dissertation tend to support the hypothesis that the neighborhood socioeconomic environment significantly influences cardiorespiratory fitness and physical activity in youth. In general, lower cardiorespiratory fitness and physical activity levels were observed among youth residing in areas of concentrated socioeconomic deprivation. While, the findings of study two did not support the hypothesis of this dissertation, we believe that limitations in study design and statistical power likely contributed to these findings. Further, this dissertation addressed several gaps in the literature and highlights the need for additional studies to better understand this complex relationship.

Limitations

This dissertation has several limitations that should be noted. First, the specific individual- and neighborhood-level characteristics used in each study were limited to those that were measured in the existing data sets and/or available via public data sources. It is possible that some influential predictors were not included in the proposed analyses due to this limitation. Second, the data sets used in study one and study two were cross-sectional. This study design prevents the researchers from making causal inferences about the relationship between indicators of the neighborhood socioeconomic environment and cardiorespiratory fitness.

The remaining limitations are specific to the methods and/or measures employed to collect the outcome and primary exposure variables. In study one, school staff administered established field test to assess cardiorespiratory fitness. Training on how to administer the field test was provided; however, measurement bias may be present due to variations in the test administration. Concerning the assessment of physical activity, limitations for both objective and subjective measures should be noted. While accelerometry provides an objective measure of physical activity, the devices are limited in their ability to capture non-weight bearing and water-based activities. Further, the devices cannot capture contextual information (i.e., type and location) about physical activity behavior. Subjective physical activity measures are prone to inaccurate estimates of activity for several reasons including recall bias and social desirability (8, 9). As such, youths' self-report activity levels may be overestimated or underestimated. Additionally, typical physical activity behaviors may not have been captured due to the short time interval (i.e. one week) in which physical activity was assessed. Further, our measure of the built environment was limited to the presence of physical activity facilities. Several other built environment characteristics such as walkability and pedestrian infrastructure could also be relevant. Finally, the use of residential census tracts is not a perfect measure of and individual's neighborhood. However, current recommendations to assess neighborhood socioeconomic environment were used in this dissertation (10, 11).

Practical Implications

The results of this dissertation have practical implications for public health efforts to improve cardiorespiratory fitness and physical activity in youth. Specifically, public health practitioners can use these findings to: 1.) guide identification and prioritization of at-risk communities for public health intervention; and 2.) help tailor public health approaches to enhance effectiveness and address emerging disparities in physical activity and cardiorespiratory fitness.

First, the findings of this dissertation demonstrate the adverse impact of residing in socioeconomically deprived neighborhoods on physical activity behaviors and fitness levels in youth. An implication for these results includes targeting physical activity interventions to youth residing in socioeconomically deprived neighborhoods. More specifically, community organizations, non-profits, and government agencies should be encouraged to consider the degree of neighborhood socioeconomic deprivation when making decisions regarding allocation of resources. For instance, such organization can incorporate a measure of socioeconomic deprivation into decision making processes to identify youth at increased risk for poor cardiorespiratory fitness and activity levels. Such changes to existing decision-making practices can help to prioritize delivery of physical activity interventions and infrastructure improvements in disadvantaged communities. This multi-level approach accounts for youth's neighborhood environment in addition to individual level factors and may have the potential to reduce emerging disparities in physical activity and fitness levels during youth.

Additionally, the findings of this dissertation suggest that youth physical activity interventions may have limited impact without consideration of environmental context. While environmental changes that address upstream social and economic factors that contribute to health disparities should be prioritized, these changes often require substantial resources over an extended period of time. As such, public health practitioners and researchers should consider more feasible and timely approaches to promote physical activity in these disadvantaged communities. Notably, however, evidence-based interventions to promote physical activity in youth may have reduced effectiveness in socioeconomically disadvantaged neighborhoods.

Within these communities, additional resources and/or tailoring of traditional one-size-fits-all interventions to improve physical activity (and cardiorespiratory fitness by extension) may be required in order to achieve the desired outcomes (12, 13). For example, a park prescription program to promote outdoor physical activity may have limited impact among youth living in socioeconomic deprived neighborhoods due to limited availability and accessibility of parks (i.e., distance, poor pedestrian infrastructure, limited transportation options). Additional issues such as safety, crime, and aesthetics my also limit uptake of the program. To gauge the potential effectiveness of such interventions, public health practitioners may need to work closely with residents to identify existing barriers and prioritize approaches to improve youth activity levels. A community engagement approach would give youth and their families a voice in the decision-making process and allow them to identify community needs and barriers to physical activity. Such information can be used by public health practitioners to guide the tailoring and implementation of physical activity interventions. Additionally, a youth advisory council could be formed to provide a platform for youth to voice their concerns and to engage youth in efforts to improve community physical activity environment (e.g., advocate for changes via environmental justice projects such as Photovoice).

In summary, the potential implications of these findings are important. The strategies described above offer some potential solutions to address low cardiorespiratory fitness and physical activity levels in youth residing in socioeconomically deprived neighborhoods. However, these efforts will require thorough evaluation to determine their effectiveness. Continued evaluation of these efforts will help to further refine physical activity interventions for youth residing in socioeconomically deprived communities.

Considerations for future studies

The results of this dissertation support a relationship between neighborhood socioeconomic deprivation, cardiorespiratory fitness, and physical activity in youth. Still, the pathways explaining how neighborhood socioeconomic deprivation may influence cardiometabolic health are not well understood (14, 15). The potential underlying mechanisms explaining how the neighborhood socioeconomic deprivation might influence cardiorespiratory fitness and physical activity are likely complex and multifaceted. For instance, low socioeconomic and minority populations often live in socioeconomically deprived neighborhoods (16–18). Some suggest that the concentration of adverse health outcomes in deprived neighborhoods may be the result of individual-level factors that are concentrated within socioeconomically deprived neighborhoods (i.e. compositional effect) (5, 19–21). For example, individuals from lower socioeconomic status tend to live near one another and are more likely to experience poor health outcomes. However, differences in health often remain significant after controlling for individual-level characteristics. This suggests that the neighborhood environmental influences health beyond individual-level characteristics (i.e., contextual effect). For instance, neighborhood socioeconomic deprivation may impact availability of supportive physical activity resources or access to such resources due to safety concerns (e.g., gene-environment interaction due to toxic stress, crime/safety, etc.) (5, 7, 19–21). Several researchers have hypothesized that socioeconomically deprived neighborhoods may influence attributes of the built environment (21–23), which in turn could influence individual physical activity behavior (e.g. park availability may influence physical activity behavior). Further, the availability (e.g., presences of parks and supportive physical activity facilities), accessibility (e.g., free/reduced cost to facilities, open school grounds, pedestrian infrastructure), and acceptability (e.g., safety, crime, aesthetics) of physical activity resources likely influences physical activity behaviors in youth (21, 22, 24, 25). A better understanding of the influence of these factors may help to identify key leverage point for implementation of interventions targeting improvements in physical activity and cardiorespiratory fitness levels among youth residing in socioeconomically deprived neighborhoods.

As such, additional studies are needed to further investigate the potential mechanisms that may explain the relationship between the neighborhood socioeconomic environment on cardiorespiratory fitness and physical activity in youth. Specifically, future research should aim to 1) expand our understanding of the relationship between the neighborhood socioeconomic environment, cardiovascular fitness, and physical activity using rigorous study designs; 2) identify the emergence of this relationship during the life course; and 3) examine the underlying mechanisms that help to explain how neighborhood socioeconomic environment influences health (14, 15, 26). Additionally, studies examining the potential moderating effect of the neighborhood socioeconomic environment on the effectiveness of evidence-based strategies to improve youth fitness and physical activity levels are needed. Results of such studies could provide information that could be used to help tailor evidence-based approaches for improving youth cardiorespiratory fitness and physical activity levels.

Conclusions

In summary, the findings of this dissertation support a relationship between neighborhood socioeconomic environment, cardiorespiratory fitness, and physical activity in youth. However, some inconsistencies in the findings of this dissertation were observed across the three studies. Two of the three studies reported a significant relationship of the neighborhood socioeconomic environment with cardiorespiratory fitness and physical activity in youth. Null findings were reported in the remaining study. The results of this study showed that cardiorespiratory fitness decreased as neighborhood deprivation increased; however, the association was not significant. This may suggest that the non-significant finding is due to lack of statistical power. Despite the inconsistent findings of this dissertation, efforts to improve cardiorespiratory fitness and physical activity levels among youth should be prioritized. Additional studies are needed to replicate these findings and further expand the body of knowledge. A comprehensive understanding of these relationships will help to identify key leverage points for public health intervention and can inform the development of effective upstream environmental and policy strategies to promote health.

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CHAPTER 6

PROPOSAL[4]

[4] Clennin, MN, Colabianchi, N, Kaczynski, A, Sui, X, Pate, RR. Literature review to be submitted for publication to undetermined journal.

Introduction

In the U.S., health is not distributed equally across populations or geographic areas. For instance, drastic inequalities in health have been observed across neighborhoods, counties, and states (1–3). The clustering of adverse health outcomes within various geographic areas has led researchers to explore the effects of ‘place’ on health (4, 5). While previous research has identified several individual-level characteristics and behaviors that are associated with health, elements of the environment have been increasingly recognized as influential determinants of health and potential contributors to health inequalities. Hence, researchers investigating the geographic variations in health often seek to determine the role of environmental factors on health after accounting for individual-level characteristics (6–8).

A growing body of evidence has consistently reported a significant association between neighborhood socioeconomic environment and numerous health outcomes including mortality, cardiovascular disease, cancer, depression, self-reported health status, and other chronic disease risk factors (7–9). Across existing literature, evidence suggest that individuals residing in disadvantaged communities (i.e., poor neighborhood socioeconomic environment) are less likely to engage in health-enhancing behaviors and experience poorer health outcomes than individuals residing in more affluent communities. A majority of these studies have focused largely on the influence of neighborhood socioeconomic environment on broader health outcomes in adult populations. To date, limited research has examined the influence of neighborhood socioeconomic environment on health and health-related behaviors among younger populations.

The increased prevalence of poor physical fitness and physical inactivity as well as the emergence of cardiometabolic disease risk factors during adolescence warrants significant attention from public health professionals (10–13). While efforts to improve poor fitness and physical activity levels have increased, limited research has examined the relationship between indicators of neighborhood socioeconomic environment, cardiorespiratory fitness, and physical activity among youth. The underlying mechanisms explaining how the neighborhood socioeconomic environment might influence cardiorespiratory fitness and physical activity are complex and multifaceted. For instance, characteristics of the socioeconomic environment could directly influence physiological responses to environmental stressors and/or indirectly by influencing features of the built environment and health-related behaviors. To date, however, the independent influence of the neighborhood socioeconomic environment on cardiorespiratory fitness and physical activity among adolescents remains relatively unexplored. Additionally, limited research has examined how the neighborhood socioeconomic environment interacts with elements of the built environment to influence cardiorespiratory fitness and physical activity among adolescents.

Statement of the Problem

The overarching goal of this dissertation is to describe how characteristics of neighborhood socioeconomic environment and elements of the built environment are associated with cardiorespiratory fitness and physical activity in diverse samples of adolescents. The specific aims and objectives to address this overarching goal are outlined below.

Aim 1: To describe the association between socioeconomic environment and cardiorespiratory fitness levels in a diverse sample of students.

Objective 1A: To describe the association between the socioeconomic environment and cardiorespiratory fitness levels.

Objective 1B: To determine if the association between the socioeconomic environment and cardiorespiratory fitness varies across age, sex, race/ethnicity, and socioeconomic subgroups.

Aim 2: To describe the relationships among neighborhood socioeconomic environment, physical activity, and cardiorespiratory fitness levels in a nationally representative sample of U.S. adolescents (12-15 years old).

Objective 2A: To describe the association between neighborhood socioeconomic environment and cardiorespiratory fitness in a nationally representative sample of U.S. adolescents.

Objective 2B: To determine if physical activity mediates the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness in a nationally representative sample of U.S. adolescents.

Aim 3: To describe the longitudinal associations of neighborhood socioeconomic environment and elements of the built environment with physical activity in youth during the transition from childhood to adolescence.

Objective 3A: To determine if physical activity is spatially clustered within neighborhoods as youth transition from childhood to adolescence.

Objective 3B: To determine if neighborhood socioeconomic environment is associated with changes in physical activity as youth transition from childhood to adolescence.

Objective 3C: To determine whether elements of the built environment moderate the relationship between neighborhood socioeconomic environment and changes in physical activity as youth transition from childhood to adolescence.

Scope

The aims and objectives outlined above will be addressed by analyzing data from three existing observational studies: 1) South Carolina FITNESSGRAM, 2) NHANES National Youth Fitness Survey (NNYFS), and 3) Transitions and Activity Changes in Kids (TRACK) Study. Aim 1 of this dissertation will utilize data from the South Carolina FITNESSGRAM, a state-wide project to evaluate and ultimately improve health-related fitness among 740,000 public school students in South Carolina. To address Aim 2 of this dissertation, data from the 2012 NNYFS will be utilized. The NNYFS was conducted in conjunction with the 2012 NHANES to compile physical fitness and physical activity information on a nationally representative sample of non-institutionalized youth (3-15 years). For the purposes of this study, the NNYFS sample will be restricted to adolescents (12-15 years). Finally, longitudinal data from the TRACK study will be utilized to address Aim 3. TRACK is a multi-level, longitudinal study examining factors influencing changes in physical activity as youth transition from elementary to middle school. Youth were recruited from 21 public elementary schools in two school districts in South Carolina.

Generalizability of the findings for each aim will vary due to differences between the selected data sources. The NNYFS includes a nationally representative sample of non-institutionalized adolescents. As such, the scope of Aim 2 will be limited to all 12-15-year-old non-institutionalized adolescents in the U.S. The generalizability of the findings from the remaining aims will be more restricted. Specifically, the scope of Aim 1, which will utilize data from the South Carolina FITNESSGRAM project, will be limited to youth (grades 5 through 12) attending schools that participated in the project during school year 2015-2016. Finally, the scope of Aim 3 will be limited to youth residing in the two South Carolina communities observed in the TRACK study (grades 5 through 7).

Assumptions:

1. The submaximal exercise test (NNYFS) and the pacer (FITNESSGRAM) provide valid estimates of cardiorespiratory fitness, which is the primary outcome for Aims 1 and 2.
2. Self-reported physical activity provides an accurate estimate of total weekly MET-minutes (Aim 2).
3. Accelerometry is a valid estimate of physical activity and the cutpoints applied to the data result in valid classification of activity levels (Aim 3).

4. Census tract is an appropriate area-level unit to assess an adolescent's socioeconomic environment (Aims 1, 2 and 3).

Significance

Across existing literature, research has consistently reported poorer health outcomes among individuals from lower socioeconomic backgrounds. Such disparities in health do not occur at random but result from differential exposure to environmental factors that either promote or deter health-related behaviors and outcomes. The persistent concentration of poor health outcomes in disadvantaged areas suggests that local environmental factors, such as the neighborhood socioeconomic environment, may play a significant role in influencing health. Previous research has demonstrated that not all communities and neighborhoods offer the same resources and opportunities for health. These same communities are often limited in their ability to deliver traditional one-size-fits-all public health interventions. Hence, public health professionals and researchers must consider alternate approaches to promote health in these disadvantaged communities and neighborhoods.

While many public health initiatives have the same desired goal for each individual in the population, it is imperative that public health professionals account for the contextual factors in the environment that will influence the effectiveness of initiatives designed to improve health. This concept is referred to as *proportionate universalism* and applies an equity lens to traditional efforts to promote health across the entire population. For example, socioeconomically disadvantaged neighborhoods may require additional resources and/or tailored interventions in order to achieve the desired health outcome. Prior to tailoring interventions according to environmental context, researchers must understand the underlying mechanisms driving the geographic distribution of health disparities and how such mechanisms influence efforts to improve health.

Given the increased prevalence of physical inactivity and poor physical fitness during adolescence, it is of great relevance to understand the influence of the socioeconomic environment on these risk factors for disease. The proposed dissertation will determine how characteristics of neighborhood environment are associated with cardiorespiratory fitness and physical activity during adolescents. More specifically, this dissertation will build on previous literature by examining the association of multiple attributes of the socioeconomic environment with cardiorespiratory fitness and physical activity in diverse samples of adolescents. A comprehensive understanding of this relationship will better inform the development and implementation of effective environmental and policy interventions targeting improvements in physical activity and cardiorespiratory fitness levels.

In closing, inequalities in socioeconomic environments are identified as a driver of health disparities and pose a serious challenge to the effectiveness of health interventions. As such, research that aims to understand how the socioeconomic environment influences health and intervention effectiveness is needed to address growing health disparities among adolescents. The proposed research is significant because it will provide crucial information that can help to understand mechanisms driving the growing inequality in activity levels and declining fitness levels among this population**.** This research will address significant gaps in the literature and represents a logical and important step in understanding the influence of the socioeconomic environment on health. Further, the results can be used to develop more effective strategies to improve physical activity and fitness levels among adolescents, especially those from socioeconomically disadvantaged backgrounds.

Limitations

There are several limitations of the proposed dissertation that should be noted. First, the specific individual- and neighborhood-level characteristics used to address each aim will be limited to those that were measured in the existing data sets and/or available via public data sources. It is possible that some influential predictors will be not included in the proposed analyses due to this limitation. Second, the data sets used to address Aims 1 and 2 are cross-section in design. This study design prevents the researchers from making causal inferences about the relationship between indicators of the neighborhood socioeconomic environment and cardiorespiratory fitness.

The remaining limitations are specific to the methods and/or measures employed to collect the outcome and primary exposure variables. In the FITNESSGRAM project, school staff administered the PACER test to collect cardiorespiratory fitness data. Training on how to administer the PACER was provided; however, measurement bias may be present due to variations in the test protocol. Concerning the assessment of physical activity, limitations for both objective and subjective measures should be noted. While accelerometry provides an objective measure of physical activity, the devices are limited in their ability to capture non-weight bearing and water-based activities. Further, the devices cannot capture contextual information (i.e. type and location) about physical activity behavior. Subjective physical activity measures are prone to inaccurate estimates of activity for several reasons including recall bias and social desirability (14, 15). As such, adolescents' self-report activity levels may be overestimated or underestimated. Additionally, typical physical activity behaviors may not have been captured due to the short time interval (i.e. one week) in which physical activity was assessed. Finally, the use of residential census tracts is not a perfect measure of neighborhood. However, spatial analytic techniques will help to address this limitation by including information from neighboring census tracts.

Literature Review

Poor physical fitness and physical inactivity are well-documented risk factors of chronic disease and premature death (16–19). In particular, cardiorespiratory fitness is considered to be one of the most important markers of health and a strong predictor of morbidity and mortality for cardiovascular diseases and all-cause mortality (20–24). Considerable evidence suggests that chronic diseases, such as cardiovascular disease, originate in childhood and adolescence (12). The increased prevalence of physical inactivity and poor physical fitness as well as the emergence of risk factors for several metabolic and cardiovascular diseases during adolescence warrants significant attention from public health professionals. Existing literature has highlighted the importance of environmental influences on health-related behaviors and outcomes, especially the socioeconomic environment (25–29). The following review of the literature first examines aspects of cardiorespiratory fitness and physical activity during adolescence and then summarizes the current knowledge regarding their relationship with the broader socioeconomic environment.

Adolescence.

In 2015, there were roughly 42 million adolescents (10-19 years old) in the U.S.; representing approximately 13 percent of the population (30, 31). Adolescence is a formative life stage characterized by rapid physical, emotional, intellectual, and psychological development (30, 32, 33). During this crucial developmental period, the rate change is significant and second only to changes observed during early childhood (33). Adolescence is also a key period for the adoption of health-related behaviors, such as physical activity (30). Previous literature suggests that health behaviors established during adolescence can track strongly into adulthood and are major determinants of health across the lifespan (34–37). Health inequalities have also been observed to emerge during adolescence (32). Globally, researchers have identified several structural factors such as national wealth, access to education, and income inequality as the primary drivers of health inequality during adolescence (33). At the individual level, socioeconomic status has been identified as a major determinant of adolescent health (32). Unfortunately, recent evidence suggests that health inequalities during adolescence are widening (32). These growing disparities will likely translate to larger inequalities in adult health during the coming decades (32). Given that adolescence is a crucial development stage in which widening health inequalities have been documented, public health professionals should prioritize 1.) the promotion of health enhancing behaviors and 2.) the identification of modifiable drivers of health inequalities among adolescents.

Adolescence and Cardiorespiratory Fitness.

Physical fitness is a state or condition that is defined as an individual's capacity to perform physical activity and/or carry out tasks of daily living without undue stress (38, 39). The components of health-related physical fitness include cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, and body composition (40). Some recent assessments have also included morphological (e.g., waist circumference, waist to hip ratio) and metabolic (e.g., blood lipid levels, glucose) components (41). While all components of health-related fitness are important, research has consistently identified cardiorespiratory fitness as the component most strongly associated with health outcomes (42).

Cardiorespiratory fitness is a measure of maximal aerobic power. More specifically, it is a measure of the body's cardiovascular and respiratory systems capacity to supply fuel and sustain prolonged strenuous physical activity. Maximal oxygen consumption, or VO_2max, represents the maximal rate of oxygen uptake and delivery to working tissues during physical activity and is typically expressed as the volume of oxygen consumed per unit of time relative to body mass ($ml \cdot min^{-1} \cdot kg^{-1}$) (39, 43, 44). During adolescence, cardiorespiratory fitness changes independent of physical activity levels (40). On average, VO_2max begins to increase around age eight and continues to increase until approximately age 16 years in males and age 13 years in females (45).

Cardiorespiratory Fitness and Health. Cardiorespiratory fitness is considered to be one of the most important markers of health. Research has well-documented cardiorespiratory fitness as a strong predictor of morbidity and mortality for cardiovascular disease and several other chronic conditions (20–23). Among children and adolescents, strong evidence suggests that cardiorespiratory fitness is already a powerful marker of health during these early life stages and likely a stronger predictor of health than body composition (11, 39, 46-47). Previous research has consistently documented the strong association of cardiorespiratory fitness in youth with total and abdominal adiposity as well as traditional and emerging cardiovascular disease risk factors such as high blood pressure, high cholesterol, high fasting glucose, and high fasting insulin levels (39, 46, 48–51). Some recent studies have also suggested that cardiorespiratory fitness may have a positive effect on mental health outcomes such as depression, anxiety, self-esteem, and academic performance (39, 46). Longitudinal studies have also reported that adequate levels of cardiorespiratory fitness in youth are significantly associated with adiposity and cardiometabolic health in adulthood (47, 51–53).

Prevalence. Globally, fitness levels among U.S. youth (9-17 years old) rank poor compared to other countries (11, 54). The most recent comparison ranked U.S. youths' performance on the 20-meter shuttle run 47th out of 50 countries (11). Based on the most recent estimates from the 2012 NHANES National Youth Fitness Survey (NNYFS), approximately 42% of U.S. adolescents (12-15 years old) had an adequate level of cardiorespiratory fitness, as determined by age- and sex-specific thresholds (10, 55). Similar to earlier assessments, cardiorespiratory fitness was found to be higher among males and normal weight youth compared to their respective counterparts (10, 46, 56). In the U.S., no significant differences in cardiorespiratory fitness were found across race/ethnicity groups (10, 56). However, findings regarding the relationship between socioeconomic status and fitness among adolescents are inconsistent in the literature (10, 46, 57). While nationally representative data suggest that adolescent/family socioeconomic status is not associated with cardiorespiratory fitness (10), other studies have reported significantly lower levels of fitness among low socioeconomic youth (46, 57, 58).

Secular Trends. Existing data suggest cardiorespiratory fitness in youth has declined over the past decades; specifically, in measures of endurance such as distance runs (10, 38, 59, 60). Across 11 developed countries, a meta-analysis examining the performance of youth (6-19 years old) on the 20-meter shuttle run from 1981-2000 reported significant declines in performance across most age and sex groups. The sample weighted decline in performance on the 20-meter shuttle run was estimated to be -0.43% per year (61). While the rate of decline in performance was similar among males and females, the decline was greater among older adolescents (15-19 years; -1.0% per year) compared to younger youth (6-14 years; -0.4%/year). The authors concluded that rapid decline in performance on the 20-meter shuttle run might be attributed to lower levels of aerobic fitness (i.e., as a result of lower levels of vigorous physical activity) and/or increases in youth adiposity (61).

More recent evidence in the U.S. and UK suggest that the annual rate of decline in cardiorespiratory fitness in youth is accelerating (10, 59, 60). In the U.S., the percentage of youth age 12-15 years old with adequate levels of cardiorespiratory fitness was found to decrease significantly from 52.4% in 1999-2000 to 42.2% in 2012; an average decline of -0.78% per year. By sex, the decline in cardiorespiratory fitness from 1999 to 2012 was significant among boys (-14.6%), but not girls (-6.7%). Similar trends in cardiorespiratory fitness have been observed among a sample of 10-year-olds in the UK. Notably, these findings were the first to show that declines in cardiorespiratory fitness may be largely independent of changes in body composition (59, 60).

Determinants. Cardiorespiratory fitness is determined by a set of attributes that an individual has (non-modifiable) or achieves (modifiable) that impact the ability to perform physical activity (43). It is, in part, genetically determined; however, it is also heavily influenced by environmental factors. Relatively little is known regarding the factors that influence cardiorespiratory fitness beyond individual-level characteristics (e.g., genetics, age, sex) and behaviors (e.g., physical activity).

A substantial portion of the variance in cardiorespiratory fitness during adolescence is accounted for by an individual's size, physique, body composition, and maturity status (45). However, there is still a considerable amount of variation that is not accounted for by these factors. Specifically, habitual physical activity has been identified as one of the primary modifiable determinants of cardiorespiratory fitness (39, 42). While physical activity is assumed to be related to physical fitness, research examining the relationship between habitual physical activity and components of physical fitness generally report low to moderate associations in adolescents (62–64). Previous research as shown that physical activity accounts for a relatively small portion of the variance in some components of physical fitness (65–67). However, the association between physical activity and cardiorespiratory fitness is consistently stronger, suggesting that the effects of habitual physical activity may be specific to cardiorespiratory fitness (65, 68–71).

Among youth, cross-sectional and longitudinal studies have shown a positive association between habitual physical activity and cardiorespiratory fitness (65, 69–71). Notably, the intensity of physical activity likely produces different effects on cardiorespiratory fitness. One study of adolescents reported an association between vigorous physical activity (>6 metabolic equivalents (METS)) and higher levels of cardiorespiratory fitness; no association was observed at light or moderate activity levels (72). Other studies have reported higher levels of cardiorespiratory fitness among adolescents that accumulate at least 60 minutes per day of moderate-to-vigorous physical activity, independent of adiposity status or screen time behaviors (73–75). Cardiorespiratory fitness has also been found to act as a mediator in the relationship between physical activity and health-related outcomes in adolescents (76, 77).

Adolescence and Physical Activity.

Physical activity is defined as *"bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure"* (16). Regular physical activity is considered to be one of several factors known to influence healthy growth and development during adolescence (78). Research suggests that physical activity levels remain relatively stable or increase slightly until approximately 12 to 14 years of age. During the transition from childhood to adolescence, physical activity levels are typically observed to decline precipitously (13, 38, 79–81). While declines in activity are observed across all intensity levels, the most marked declines have been reported at vigorous intensity physical activity levels; which is estimated to decrease by 29% and 36% in males and females, respectively (80). The patterns of physical activity also change during the transition into adolescence. In general, children's activity patterns tend to be sporadic in nature with an estimated 66% of total moderate-to-vigorous physical activity being accumulated in short intermittent bouts (82). During adolescence, activity patterns tend to become more organized and increase in duration compared to the irregular activity patterns characteristic of children (38).

Physical Activity and Health. The immediate and long-term health outcomes associated with physical activity are well-document. Among adolescents, engaging in the recommended amount of physical activity is associated with numerous health-related outcomes including improved cardiometabolic health, muscular fitness, and favorable body composition (83–90). Further, recent evidence support a dose-response relationship between moderate-to-vigorous physical activity levels and the presences of multiple cardiometabolic risk factors (91–95). Hence, early establishment and maintenance of habitual physical activity across the lifespan can produce a significant impact on population mortality and longevity (96).

Measurement. Physical activity is can be measured via a range of subjective and objective methods; each with inherent strengths and limitation (97–99). Subjective techniques allow researchers to collect information regarding the amount (i.e., frequencies, intensity, and duration) and type of physical activity performed as well as context in which the behavior occurred. Examples of subjective measurement methods include individual self-report of physical activity via questionnaires, interviews, activity logs/diaries, etc. While cost-effective and easy to administer to large samples, subjective measurement of physical activity can also introduce bias into the data. Previous research has well-documented the over- and underestimation of physical activity due to social desirability bias, recall bias, and differential interpretation of instrument questions (91, 100–102).

Physical activity can also be measured objectively via device-worn monitors (e.g. pedometers, accelerometers) and direct observation. While device-worn monitors do not capture the type of physical activity or the context in which physical activity occurs, objective measures may provide a more accurate assessment of physical activity levels (103). However, accelerometers can also introduce bias due to underestimation of activity levels. Accelerometers cannot account for certain physical activity behaviors (e.g., swimming, non-locomotion movements) and may not capture physical activity performed when the device is not worn. Further, despite established cutpoints, it is important to note that intensity levels for the same activity can vary by individual. Comparing self-report and objective measures of moderate-to-vigorous physical activity, previous studies have documented a weak but positive correlation between the two measures with self-reported activity levels tending to be substantially higher than device-based estimates of activity (104).

Prevalence. Despite significant public health efforts to increase physical activity, objective evidence suggests that an overwhelming majority of adolescents (12-19 years) are failing to meet U.S. Physical Activity Guidelines, which call for 60 minutes of daily physical activity. The most recent nationally representative data using objective measures of physical activity estimate that only six to eight percent of adolescents meet the daily 60-minute recommendation (13). In general, the following demographic subgroups are less likely to meet the 2008 Physical Activity Guidelines compared to their respective counterparts: females, older youth (12-19 years old), overweight/obese youth, and females of lower socioeconomic status (79). The largest and most consistent differences in physical activity occur between gender and age groups. A precipitous decline in physical activity is typically observed during the transition from childhood (6-11 years old) to early adolescents (12-15 years old). By late adolescence (16-19 years old), moderate activity levels tend to be low and levels of vigorous activity become negligible (13).

Concerning gender, male adolescents tend to exhibit higher activity levels compared to their female counterparts (13, 79, 80, 105, 106). For instance, previous estimates show that males accumulate an average of 45 minutes of moderate-to-vigorous physical activity per day during early adolescents and 33 minutes during late adolescence (13). Similar patterns were observed among females with an estimated 25 and 20 minutes of moderate-to-vigorous physical activity per day during early and late adolescence, respectively. While males are typically observed to be more active than females across the lifespan, evidence suggests that the gender gap in physical activity widens during adolescence (13).

Findings on differences in physical activity across race/ethnicity and socioeconomic groups are inconsistent and vary by the type of physical activity measure used. Across racial/ethnic groups, earlier studies using self-report instruments reported lower physical activity levels among non-Hispanic black youth compared to non-Hispanic whites (105, 107–111). Other studies using objective measures of physical activity (e.g., accelerometry) have reported no difference across race/ethnicity groups and in some cases lower activity levels among non-Hispanic white adolescents compared to other race/ethnicity subgroups (13, 79, 106, 112). While differences in activity levels have been observed in children and young adolescents, recent evidence suggest that differences in moderate-to-vigorous physical activity across race/ethnicity groups dissipate by late adolescents (16-19 years old) (79).

Evidence examining the relationship between physical activity and socioeconomic status among adolescents is far from uniform (106, 109, 113). Some studies have reported no differences in physical activity across socioeconomic groups (106). However, recent reviews noted that while inconsistencies exist, a majority of studies support the existence of a positive relationship between socioeconomic position and physical activity among adolescents (113, 114). Stalsberg and colleagues (2010) noted that 42% of the studies included in their review reported null or negative findings (113). In general, however, evidence suggested that adolescents from lower socioeconomic levels accumulate significantly less physical activity compared to their more affluent counterparts. Of greater concern are recent findings that suggest inequities in adolescent activity levels have widened by 4-10% across socioeconomic groups over the past decade (32, 115).

Secular Trends. Historically, more emphasis has been placed on the assessment of physical fitness in youth. During the 1980s, the first large scale assessments of physical activity in children and youth were conducted. Hence, the examination of trends in adolescent physical activity is limited due to the lack of surveillance data over time (78). Across existing studies, the assessment of trends in physical activity is further limited by significant variations in data collection methodologies (i.e., measurement, protocols, etc.) (38). While surveillance data examining trends in physical activity is limited, the use of nontraditional data sources suggests that habitual physical activity among youth has declined over the past four decades or so (38, 78, 110, 116). One recent review reported declines in youth physical activity across several domains including active transportation, school-based physical education, and outdoor play (116). Further, advances in technology have increased opportunities for youth to substitute sedentary behaviors for more traditional physical activity behaviors (38, 116). Despite limitation in our ability to definitively examine trends in youth physical activity levels, available information indicates that physical activity levels among youth are perilously low and decreasing progressively over time (78).

Determinants and Correlates. Physical activity is a complex and multi-dimensional behavior that is influenced by biological, psychological/cognitive, sociocultural, and environmental factors (78, 81, 117). A recent review of systematic reviews examining the correlates of physical activity among children and adolescents identified 15 variables that were consistently associated with physical activity among adolescents (117). Of those, five demographic variables consistently had a positive association with physical activity (i.e., male, non-Hispanic white, parental education, family income, and socioeconomic status). Age was found to be inversely associated with activity levels. Concerning psychological/cognitive variables, the review indicated that perceived competence, self-efficacy, motivation, attitudes, and perceived barriers for physical activity were consistently associated with physical activity in adolescents.

Behavioral and social/cultural factors associated with physical activity in adolescents were participation in community and/or organized sport programs and parent support for physical activity. Finally, several features of the physical environment, specifically access to facilities, programs, and/or recreational areas that support physical activity, were found to be positively associated with activity levels among adolescents (117). The identified factors likely interact in a synergistic manner across different levels of influence (81, 117).

While existing literature has identified numerous determinants and correlates of adolescent physical activity levels, the environment is hypothesized to be one of the greatest influences on activity levels during this life stage (78, 118).

Environment Influences on Cardiorespiratory Fitness and Physical Activity.

Existing literature has extensively examined individual-level determinants and behavioral interventions to improve cardiorespiratory fitness and physical activity levels (38, 39, 81, 117). However, recent literature and conceptual frameworks have noted the importance of environmental influences on health-related behaviors and outcomes (25–27, 119). Evidence suggest that the influence of the environment on health and health-related behaviors may increase during adolescence as youth become increasingly independent and gain more responsibility (120, 121). A myriad of influences at the environmental level, including physical, social, and socioeconomic factors, are thought to have a profound impact on adolescents current and future health status (27, 120).

Theoretical Frameworks and Social Ecological Models.

A social ecological perspective focuses on the influence of one's environment on health outcomes and health-related behaviors in addition to individual-level determinants (29). Social ecological models can be distinguished from traditional behavior change models by their inclusion of multiple levels of influence on health, including intrapersonal (e.g., psychosocial and physiological characteristics), interpersonal, organizational, community, and policy (25, 29, 122, 123). This approach also acknowledges the interaction between influences of health and health-related behaviors across different levels. More specifically, ecological models acknowledge that behavior is a product of an individual's interaction with their environment and that both individuals and the environment likely exert influence on one another (124). The inclusion of multiple levels of influence allows social ecological models to provide a comprehensive understanding of the factors influencing health (125). However, while ecological models have greatly advanced the conceptualization and understanding of factors that influence health and health-related behaviors, more work is needed to identify underlying mechanisms that might help to explain the complexities of the environment-health relationship. To address some of these complexities, general social ecological models have been adapted to focus on specific health outcomes and/or health-related behaviors, such as chronic diseases, obesity, and physical activity (26–28, 122, 126, 127).

Proposed pathways between socioeconomic status and youth health outcomes model. Schreier and Chen (2013) built on existing social ecological frameworks to examine the persistent association between socioeconomic status and youth health outcomes (28). The proposed model aimed to advance the understanding of the influences of socioeconomic status on youth health while examining the influence of socioeconomic status across multiple levels simultaneously. The model depicts the proposed pathways through which socioeconomic status could influence youth health at the neighborhood-, family-, and individual-levels. Influences at the neighborhood- and family-level are broken down into social and physical environment exposures. The factors identified at each level are hypothesized to operate in a bidirectional and synergistic manner to influence youth health outcomes. For instance, the authors noted that 1.) factors at one level could influence the socioeconomic-health relationship at lower levels (i.e., spillover/synergistic effect represented by unidirectional arrows) and 2.) factors at two different levels could have reciprocal effects on each other (i.e., feedback loop represented by bidirectional arrows). The proposed framework highlights multiple levels of influences that could be driving socioeconomic disparities in health.

Ecological Model for Active Living. Sallis and colleagues (2006) built on previous ecological models of physical activity to develop an ecological model for active living (27, 119, 128–130). Their model is organized around four domains of active living: active recreation, active transportation, occupational activities, and household activities (125). Across each domain, multiple levels of influence are identified. In the center of the model, the individual is represented with broad categories of intrapersonal variables. Next, individual perceptions of the environment are depicted in the second ring of the model. These are distinguished from more objective measures of the environment, which are represented in the ‘Behavioral Settings: Access and Characteristics’ ring of the model. Finally, the most outer ring represents the policy environment, which has the potential to influence physical activity through several mechanisms including built environment infrastructure and programs. The framework also identifies the social cultural, information, and natural environments as influential to physical activity behavior. Collectively, this framework highlights the importance of a multilevel approach across multiple disciplines to address the complex interactions and influences of physical activity. While not explicitly depicted in the model, the broader socioeconomic context exerts an influence across multiple levels and domains of active living to influence physical activity behavior (27).

Environmental Justice Framework. Finally, an environmental justice perspective considers both the broader socioeconomic environment and the built environment with respect to the distribution of health outcomes. Traditionally, environmental justice focused on the fair treatment of all individual with respect to development, implementation, and enforcement of environmental laws (131). More recently, however, the environmental justice movement has shifted its focus toward issues related to urban design, public health, and access to health-enhancing resources (132). Under this framework, geographic variations in health are hypothesizes to be the results of unequal distribution of health-enhancing and health-deterring built environment characteristics across neighborhoods with varying socioeconomic status (133). The available evidence suggests that the distribution of environmental characteristics can play an influential role in driving geographic health disparities (133).

Environmental justice principles emphasize protection of all individuals from environmental exposures with known adverse health impacts regardless of socioeconomic status (134). Two key principles include: 1.) environmental exposures are not distributed equally across socioeconomic environments (i.e., socioeconomically deprived neighborhoods are less likely to have environmental supports for health); 2.) individuals and neighborhoods/ communities with a lower socioeconomic position are more vulnerable to adverse environmental exposures (135). An example of an ecological conceptual model derived from an environmental justice framework is Gee and Payne-Sturges (2004) exposure-disease-stress framework, which depicts the relationship between race, environmental exposures, and health disparities (136).

The identified conceptual models and the theoretical framework emphasize the importance of examining the independent influence of the socioeconomic environment on health as well as its influence on the relationship between neighborhood-, family-, and individual-health outcomes. It is likely that factors at different levels interact in a synergistic manner; supporting the use of socioecological models (117). To intervene effectively on perilously low fitness and physical activity levels among U.S. adolescents, a deeper understanding of the multi-level factors influencing health is needed, especially at the environmental-level. The three ecological frameworks outlined above were influential in the development of the conceptual model that informed the conceptualization of the aims for this dissertation.

Spatial Clustering of Health and Health-Related Behaviors in Neighborhood.

In the U.S., health is not distributed equally across populations or geographic areas. Inequalities in health have been observed across geographic areas including neighborhoods, counties, and states. However, the most stark spatial inequalities are often observed within cities and across neighborhoods (137). Recent reports have captured disparities in life expectancy by as much as 25 years between neighborhoods separated by only a few miles (1, 2). Others have noted that a child's zip code might better predict long-term health outcomes than genetics (3, 138). The Centers for Disease Control and Prevention defines clustering of health events as *"an unusual aggregation, real or perceived, of health events that are grouped together in time and space..."* (139). This clustering of adverse health outcomes within various geographic areas has led researchers to explore the effects of 'place' on health (4–8). More specifically, research examining how the neighborhood and broader socioeconomic environments affect health has increased during the past two decades (6, 7).

Several factors have contributed to the increased interest in the relationship between place and health (7). First, focus solely on individual-level factors has not been able to fully account for significant spatial clustering of health outcomes within geographic areas. The persistent clustering of various health outcomes suggests that the context and characteristics of the environment have an independent influence on health. Second, the spatial patterning of disease might suggest that neighborhood characteristics could significantly contribute to health inequalities across race and socioeconomic groups. Importantly, these neighborhood attributes are often amendable to change via policy and environmental interventions (140, 141). Finally, advances in analytic methodologies provide researchers with more appropriate techniques to examine the effects of place on health. Specifically, the use of multilevel and spatial analytic techniques allows researchers to account for individuals nested within neighborhoods and spatial proximity to exposures (7, 142, 143).

Neighborhood Environment.

Researchers investigating the geographic variations in health often seek to determine the role of neighborhood factors on health after accounting for individual-level characteristics of neighborhood residents. The term '*neighborhood*' is typically used to describe the immediate environment around an individual's place of residence. The definition of neighborhood is not precise but varies based on the criteria used to restrict the geographic area (5, 6, 144–146). Previous public health studies have used several methods to define an individual's neighborhood. Some examples include administrative boundaries (e.g., counties, census tracts), radial or network buffers surrounding an individual's home, and an individual's perception of his or her neighborhood boundary (e.g., interview or survey). The concept of neighborhood is used to capture the spatial context and characteristics of the environment surrounding an individual's residence that might influence the health. In particular, the socioeconomic and physical features of the neighborhood environment are hypothesized to influence health-related behaviors and outcomes (6, 7).

Dimensions of the Neighborhood Environment. Researchers have established a general distinction between compositional and contextual neighborhood effects in an effort to better understand and identify potential mechanisms underlying the relationship between neighborhoods and individual health. A compositional effect exists when inequalities in health are attributed to the individual characteristics of the neighborhood residents, such as individual socioeconomic status or health behaviors. A compositional effect is also referred to as a place or group membership effect. In this instance, neighborhood residents share similar characteristics that significantly contribute to the observed differences in health across neighborhoods. A contextual effect exists when features of the neighborhood environment, such as aspects of the socioeconomic and built environment, have an independent effect on individual-level health outcomes. A contextual effect is also referred as space or proximity effect (5, 147–149).

Across existing literature, elements of the socioeconomic and physical neighborhood environments are increasingly recognized as influential determinants of health and potential contributors to health inequalities. The neighborhood socioeconomic environment refers to the collective composition of individual-level attributes within the residential area, such as socioeconomic status, race/ethnicity, housing characteristics, material resources, etc. (7, 150). It is a complex concept that aims to represent multiple aspects of a neighborhood's socioeconomic resources (151). Evidence suggests that indicators of the socioeconomic environment tend to cluster at the neighborhood level with multiple indicators of socioeconomic disadvantage co-occurring (152–154). As such, researchers have concluded that a composite index of neighborhood socioeconomic environment is a better measure than individual indicator variables. Further, the index should be based on the neighborhoods represented in the study area and at an appropriate scale (i.e., census tract or block groups) (151).

The physical environment is further differentiated into features of the natural environment and built environment. The term natural environment is used to describe features of the environment that are unchanged and occur in nature. Built environment is defined by Schulz and Northridge as "*encompass[ing] all of the buildings, spaces, and products that are created or significantly modified by people* (…)" (127). In urban settings, this includes a vast majority of environmental characteristics as most environmental features are man-made or altered from their original state. Examples of built environment features include types of land use, street networks and connectivity, public resources, building characteristics, and pedestrian infrastructure.

Measurement. The neighborhood socioeconomic and built environments can be measured subjectively or objectively. Subjective measures are often self-reported perception of the environmental characteristics collected via questionnaires. Objective measure of the built environment can be conducted using field audits or existing land use data to capture macro-level features of the environment. Field audits of the neighborhood environment are conducted by trained researchers in the neighborhood setting. Numerous instruments have been developed to audit the built environments of the neighborhood. The data collected via field audits can range from micro-level environment features such as the presence and quality of sidewalks to macro-level features such as street connectivity and residential density. Finally, geographic software can objectively analyze existing data sources to assess macro-level features of the built environment (i.e., land use, zoning, and proximity to resources) (7, 119, 155). Similarly, neighborhood socioeconomic environment is often measured using existing data such as census characteristics, including but not limited to, racial/ethnicity and socioeconomic composition, predominant family structure, and housing tenure (7, 155).

Challenges in Neighborhood Studies. Previous research has discussed the challenges associated with examining the neighborhood-health relationship extensively (5–7). This section briefly overviews the challenges noted in existing literature: 1.) definition and measurement; 2.) residential selection and mobility; and 3.) independent vs. joint neighborhood effects on health. First, as noted above, the manner in which neighborhood is defined and operationalized is a consistent issue in this line of research. However, Diez Roux & Mair (2010) have suggested that a single ‘perfect’ definition of neighborhood does not likely exist (7). The appropriate neighborhood boundary likely varies depending on the health outcome of interest and the neighborhood characteristics thought to influence the relationship. Hence, these authors conclude that a more appropriate question is whether the definition of neighborhood applied is reasonable given the hypothesized mechanisms underlying the neighborhood-health relationship of interest (5, 7). Second, neighborhoods are dynamic entities that change over time. The selection of individuals into a neighborhood is complex and often influenced by several factors such as individual preferences and financial and material resources. Additionally, exposures across the lifespan, especially those experienced during early childhood, have been shown to influence health outcomes during adulthood (156). Longitudinal studies examining residential selection and mobility are needed to better understand the influence of neighborhood exposures on health across the lifespan. Third, neighborhood-level characteristics co-occur and likely interact with individual-level characteristics to influence health. Hence, it is difficult to determine the influence of a single factor on health. The introduction of more advanced multilevel modeling and spatial analysis techniques allows researchers to explore the synergistic effect of multiple environment- and individual-level characteristics on health. However, limitations in examining within- and cross-level interactions include small samples sizes and limited variability due to homogenous neighborhood composition (7, 117, 150).

*Neighborhoods and Health: Proposed Pathways***.** The proposed underlying mechanisms that explain the association between neighborhood environments and health are complex and interrelated. As a result, researchers have proposed several conceptual models to describe the potential pathways that neighborhood context influences individual-level health outcomes; some of which are described above (9, 27, 28, 136).

A growing body of evidence has consistently reported a positive association between neighborhood socioeconomic environment and numerous health outcomes including mortality, cardiovascular disease, cancer, depression, self-reported health status, and other chronic disease risk factors (157–168). Across existing literature, a majority of studies have focused largely on the influence of neighborhood socioeconomic status on broader health outcomes in adult populations (149). Few studies have examining the influence of neighborhood socioeconomic environment on health outcomes and/or associated risk factors during adolescence; particularly cardiorespiratory fitness and physical activity levels.

The underlying mechanisms explaining how the neighborhood socioeconomic environment might influence adolescent cardiorespiratory fitness and physical activity are complex and multi-faceted. In the U.S., neighborhoods are highly segregated by race/ethnicity and socioeconomic status, which creates areas of concentrated neighborhood deprivation (9, 137, 165). The neighborhood socioeconomic environment may directly influence fitness through physiological responses to stressors (e.g. gene-environment interaction) (7) or indirectly by influencing the neighborhood built environment and/or individual health behaviors (e.g. park availability may influence physical activity behavior). Many researchers have hypothesized that unfavorable neighborhood socioeconomic environments (i.e., neighborhood deprivation) influences the built environment (118, 149, 169), which in turn could influence individual physical activity behavior. In general, systematic reviews have concluded that there is sufficient evidence to support the relationship between features of the built environment and physical activity levels (7, 170, 171). However, few studies have considered the synergistic effect of the neighborhood socioeconomic and physical environment. Previous research has noted the that failure to account for both the neighborhood socioeconomic and built environment could result in biased estimates as neighborhood socioeconomic environment likely confounds the relationship between built environment and individual-level outcomes (172).

The remainder of this literature review will summarize research studies that examined the relationship of physical fitness and physical activity in adolescents with neighborhood socioeconomic environment. The primary purpose is to describe how characteristics of the neighborhood socioeconomic environment are related to adolescent physical fitness and physical activity levels. A secondary purpose is to identify potential mediators and describe interactions between neighborhood socioeconomic status, the built environment, and individual characteristics.

Neighborhoods Socioeconomic Environment, Physical Fitness, and Physical Activity Among Youth - Description of Studies.

Twenty-two articles examining the influence of the neighborhood socioeconomic environment, independently or in conjunction with other factors of the neighborhood environment, on physical activity and/or physical fitness among adolescents were identified. Articles were collected through detailed literature searches and analysis of reference list of identified articles. Table 6.1 provides a description of studies included in the review. Of the 22 studies identified a majority (n=19) were published in the last decade and employed a cross-sectional study design (n=17). Four of the remaining studies employed a longitudinal study design and one used repeated cross-sectional design. Most studies were conducted in the United States (n=15); followed by Europe (n=5) and Canada (n=2). Study population was restricted to adolescents (10-19 years old); 13 studies included only adolescents and 8 included adolescents in addition to younger children. Sample sizes varied considerably and ranged from 637 adolescents (173) to 163,474 youth (174) and from 25 neighborhoods (150) to 1,288 neighborhoods/communities (174). All but one study used multilevel modeling techniques controlling for individual level characteristics (58). Only one study employed spatial analytic techniques to account for spatial clustering of study participants (175).

Eighteen studies investigated the relationship between indicators of the neighborhood socioeconomic environment and one or more components of physical fitness. Specifically, one examined all components of physical fitness using objective measures (58) and 17 examined weight-related outcomes only. Weight-related outcomes included Body Mass Index (BMI) expressed as a continuous variable (n=9), overweight/obese status determined by BMI thresholds (n=8), and waist circumference and body mass (n=1). Twelve of the 18 studies used objective anthropometric measures to assess weight-related outcomes. The remaining six used self-reported measures of height and weight.

Eleven studies examining the relationship between neighborhood socioeconomic environment and physical activity were also identified; six of which also measured a weight-related outcome. Ten studies used a subjective measure of physical activity with a majority using parent- or child-reported activity. In addition, two studies used accelerometry to objectively measure adolescent activity level and minutes of moderate-to-vigorous physical activity (173, 176). Subjective measures of physical activity were inconsistent and included reported weekly bouts of moderate-to-vigorous physical activity (172, 177), physical inactivity (178, 179), number of days per week of physical activity engagement (150, 180, 181), engagement in activity during the weekend (182), sport participation (173, 183), leisure time physical activity (173), active transportation (173), and engagement in vigorous or any physical activity (183).

Across all studies examined, the measures used to assess neighborhood socioeconomic environment varied considerably with no studies employing the same measure or methodology. In general, indicators of neighborhood socioeconomic environment included measures of income, education, employment, housing and transportation, and residents' demographics. Regarding the measure of neighborhood socioeconomic environment, 12 studies calculated an index score using multiple socioeconomic characteristics of the neighborhood. The remaining studies used single variables as a measure of neighborhood socioeconomic environment, such as measures of household income, education level, unemployment rate, and racial/ethnic composition. Regarding the geographic area used to assess neighborhood socioeconomic environment, a majority of studies used U.S. census tracts or an equivalent (n=16). The other geographic measures varied and included block group, county, school enrollment zone, buffer around residence, and parent's perception of neighborhood. Eleven of the 21 studies also included a measure of neighborhood built environment, such as walkability, physical activity resources, land use, and residential density (Table 6.1).

Neighborhood Socioeconomic Environment and Physical Fitness. Eighteen studies examining the relationship between neighborhood socioeconomic environment and one or more components of physical fitness. One study examined the relationship between all components of physical fitness and indicators of neighborhood socioeconomic environment (58); the remaining 17 reported on the association between neighborhood socioeconomic environment and body composition or weight status. Sixteen of the 18 studies reported an association between indicators of the neighborhood socioeconomic environment and one or more components of physical fitness.

Association between Neighborhood Socioeconomic Environment and Components of Physical Fitness. One study examined the association between indicators of the neighborhood socioeconomic environment and all components of physical fitness using FITNESSGRAM data aggregated to the school level. The authors reported that social vulnerability, their indicator of neighborhood socioeconomic environment, was associated with each FITNESSGRAM components (BMI, aerobic capacity, upper body strength/endurance, trunk strength, and flexibility). More specifically, a lower proportion of students attending schools located in areas of high social vulnerability had adequate levels of fitness (i.e., Healthy Fitness Zone). The Social Vulnerability Index explained the most variance in aerobic capacity (boys: 26.6%, girls: 20.8%) and BMI (boys: 11.5%; girls: 16.3%) (58).

Association between Neighborhood Socioeconomic Environment and Weight-Related Outcomes. In general, a majority of the studies (n=16) supported a significant relationship between indicators of the neighborhood socioeconomic environment and youth weight-related outcomes. Ten studies examined the association between indicators of the neighborhood socioeconomic environment and body composition or weight status independent of the built environment. All ten studies reported significant associations between indicators of neighborhood socioeconomic environment; six reported an association with youth BMI (58, 174, 176, 180, 182, 184), three with weight status (120, 175, 185), and one with waist circumference and body mass (186). One study reported that youth obesity was significantly associated with two indicators of neighborhood socioeconomic environment (i.e., material wealth and unemployment rate) (180).

Another study reported the odds of overweight/obesity were 1.7 times higher among boys living in unfavorable neighborhood socioeconomic environments compared to boys living in more favorable environments. The same trend, while not significant, was observed among girls (182). Rossen (2013) reported a significant interaction between area-level deprivation and individual-level socioeconomic status with higher area-level deprivation being associated with higher odds of obesity among youth living above the poverty threshold only (185). Finally, Nevill et al. (2015) reported a strong association between neighborhood deprivation and adolescent waist circumference and body mass. However, the relationship between neighborhood deprivation and waist circumference was substantially reduced and the relationship between neighborhood deprivation and body mass was eliminated after controlling for cardiorespiratory fitness and physical activity. The authors concluded that youth living in deprived neighborhoods were less physically fit and active (186).

Three studies examined the examined the association between indicators of the neighborhood socioeconomic environment and body composition or weight status over time (121, 174, 184). Alvarado (2016) found that age and sex moderated the relationship between neighborhood socioeconomic environment and risk of obesity in youth. More specifically, neighborhood disadvantage was found to have a stronger impact on adolescents compared to younger children and on girls compared to boys (121). Another study examining Canadian reported that early neighborhood socioeconomic environment was associated with child BMI percentile over time, after controlling for individual and family-level factors. The authors found that living in low socioeconomic neighborhoods was significantly associated with higher BMI percentiles over time (184). Finally, Nau et al. (2015) reported that higher community socioeconomic deprivation, their index measures of neighborhood socioeconomic environment, was associated with higher BMI at age 10.7 years and with more rapid growth in BMI over time. The results indicated that children residing in neighborhoods with higher socioeconomic deprivation experienced a steeper acceleration of BMI during young childhood compared to children living in more favorable environments. And by age 18 years, the authors reported that the differences in average BMI of adolescents living in the most and least deprived neighborhoods (0.95) was comparable to the size of the most potent childhood obesity intervention (174).

Association between Neighborhood Socioeconomic Environment, Built Environment, and Weight-Related Outcomes. Eight of the 17 studies examined the association between indicators of the neighborhood socioeconomic environment, the built environment, and body composition (n=3) or weight status (n=5) (150, 177, 179, 183, 187–190). Of those, six studies reporting significant associations between indicators of neighborhood socioeconomic environment and body composition or weight status. One study found that the odds of obesity were 20-60 percent higher among youth living in areas characterized as the most unfavorable environments (190). Nelson et al (2006) compared six different neighborhood patterns based on the socioeconomic and built environment characteristics and found that youth living in neighborhoods characterized by low socioeconomic environments (i.e., rural working class neighborhoods, exurban outgrown, and mixed race/ethnicity urban areas) were 30-40 percent more likely to be overweight/obese compared to youth residing in new suburban developments characterized by high socioeconomic environments (177). In contrast, another study found that worse neighborhood socioeconomic indicators, specifically high unemployment rate and lower mean home surface area, were associated with a higher prevalence of obesity; however, characteristics of the built environment (i.e., number of retail stores, sport facilities, etc.) were not found to be significantly associated with obesity (179). Another study reported an inverse association between neighborhood median household income and BMI among minorities only (187). Slater et al. (2010) reported that lower neighborhood socioeconomic status, lower neighborhood safety, and higher neighborhood physical disorder were associated with increased BMI/obesity while higher neighborhood compactness was associated with lower BMI/obesity. Interestingly, the authors noted that neighborhood socioeconomic status was associated with weight but not physical activity, which led them to conclude that an alternate casual pathway may better explain the relationship between neighborhood socioeconomic status and youth BMI/obesity (183). Finally, Sharifi and colleagues (2016) found that the change in BMI over time was significantly greater among black compared to white youth and that indicators of the neighborhood socioeconomic environment did not fully attenuate the difference in BMI change over time (189).

Two studies reported no association between indicators of the neighborhood socioeconomic environment. Carroll-Scott et al. (2013) used two indices to measures neighborhood socioeconomic environment (concentrated disadvantage and concentrated advantage) in addition to measures of the built and social environment. The authors reported that pre-adolescent BMI was significantly higher among adolescents living farther from a grocery store (>1/2 mile) and in neighborhoods with more property crime. Overall, the findings supported a relationship between characteristics of the built and social environment with BMI, but not with neighborhood socioeconomic environment (150). Another study reported no association between child weight status and characteristics of the neighborhood socioeconomic and built environment. While contextual neighborhood factors were not independently related, child weight status was found to be associated with parent education, parent weight status, high birth weight, and residing in a multiple dwelling residence (188).

Neighborhood Socioeconomic Environment and Race/Ethnicity Disparities in Weight-Related Outcomes. Regarding disparities in youth obesity, four of the studies reported that the socioeconomic environment attenuated the racial/SES disparities in body composition or weight status. Grow et al. (2010) reported that approximately 24% of the geographic variability in youth obesity could be explained by indicators of neighborhood socioeconomic environment (175). Rossen (2013) reported that race/ethnicity disparities in youth obesity between White and minority youth were attenuated by 74% in non-Hispanic Blacks and 49% in Hispanics after controlling for individual demographics (185). Powell et al. (2012) reported that disparities in adolescent BMI were substantially attenuated after controlling for neighborhood socioeconomic and built environment characteristics. In fully adjusted models, neighborhood economic environment explained 13% of the disparity in BMI between Black and White females, 8% among Hispanic and White females, 28% among Black and White males, and 38% among Hispanic and White males. Overall, neighborhood economic factors explained more of the disparity is BMI among males compared to females (187). Lastly, Sharifi reported that indicators of the neighborhood socioeconomic environment attenuated the race/ethnicity disparities in BMI by 30.2% between Black and White youth and by 26.3% between Hispanic and White youth, whereas built environment characteristics attenuated the BMI disparity by 7.0% and 5.3%, respectively. While the observed racial/ethnic disparities were substantial attenuated, the differences in BMI persisted in the full adjusted model (189).

Neighborhood Socioeconomic Environment and Physical Activity.

In general, five of the 11 studies showed significant associations between indicators of neighborhood socioeconomic environment and physical activity (172, 173, 177, 178, 182). The remaining six studies reported no significant associations (150, 176, 179–181, 183) (Table 1).

Association between Neighborhood Socioeconomic Environment and Physical Activity. Four studies examined the association between indicators of the neighborhood socioeconomic environment and physical activity independent of the built environment (176, 180–182). One study reported a significant association between neighborhood deprivation (i.e., low neighborhood socioeconomic status) and adolescent's engagement in physical activity during the weekend (182). The authors observed a significant trend in physical activity across the spectrum of neighborhood socioeconomic environment, measured by the Townsend Index. Adolescent girls residing in deprived neighborhoods were significantly less likely to engage in physical activity during the weekend compared to girls living in neighborhoods with a more favorable socioeconomic environment. A similar but non-significant trend was observed among boys (182). Another study reported no association between neighborhood socioeconomic status and non-school physical activity measured objectively using accelerometry (176). The other two studies reported no association between indicators of neighborhood socioeconomic environment and the number of days per week that adolescent's reported being physically active (180, 181). In both studies, measures of individual/family-level socioeconomic status were positively associated with adolescent activity levels, but characteristics of the neighborhood socioeconomic environment were not.

Association between Neighborhood Socioeconomic Environment, Built Environment, and Physical Activity. Seven of the 11 studies examined the association between indicators of the neighborhood socioeconomic environment, the built environment, and physical activity (150, 172, 173, 177–179, 183). Of those, six studies reported significant associations; four reported a significant relationship between the neighborhood socioeconomic environment and physical activity (172, 173, 177, 178) and two reported significant associations between measures of the built environment and physical activity (150, 183).

Four studies reported a significant relationship between the neighborhood socioeconomic environment and physical activity, independent of built environment (38, 40, 44, 45, 172, 173, 177, 178). One study found that adolescents residing in neighborhoods with higher socioeconomic status reported 7 percent more moderate-to-vigorous physical activity than adolescents living in neighborhoods with lower socioeconomic status (172). Another study reported an increased likelihood of physical inactivity among adolescents residing in neighborhoods with high social fragmentation; neighborhood economic characteristics were not related (178). De Meester et al. (2012) reported that the relationship between neighborhood walkability and objectively measured physical activity varied by neighborhood socioeconomic environment. Specifically, the association only held for adolescents living in neighborhoods with low socioeconomic environments. The authors also reported no relationship between self-reported physical activity and neighborhood socioeconomic environment or neighborhood walkability. However, walking for transportation was found to be negatively associated with neighborhood socioeconomic environment (173). Lastly, Nelson et al. (2006) examined six neighborhood patterns based on combined socioeconomic and built environment characteristics. Adolescents living in older versus newer suburban areas were more likely to be physically active and adolescents in inner-city neighborhoods were more likely to be active compared to adolescents residing in mixed-race urban neighborhoods (177). In general, these findings suggest that a more supportive neighborhood built environment might play an important role in influencing physical activity when comparing neighborhoods with similar socioeconomic environment indicators.

The remaining two studies showed significant associations between measures of the built environment and physical activity independent of neighborhood socioeconomic status. Carroll-Scott and colleagues (2013) reported significant positive associations between the number of days per week that adolescents reported at least 30 minutes of physical activity and perceptions of access to parks, playground, and gyms as well as neighborhood social ties. In general, the authors reported that characteristics of the neighborhood built and social environment were associated with physical activity, but that neighborhood socioeconomic environment was not associated (150). Similarly, Slater et al. (2010) found positive associations between physical activity and neighborhood physical activity outlets and safety, and an inverse relationship between neighborhood physical disorder and sport participation. Median household income, the indicator for neighborhood socioeconomic status, was not associated with any of the examined measures of physical activity despite its significant association with adolescent weight status (183). The remaining study reported no significant association between physical inactivity and neighborhood socioeconomic environment and/or the presence of physical activity-related facilities (179).

Summary and Conclusions.

The increased prevalence of physical inactivity and poor physical fitness as well as the emergence of risk factors for several metabolic and cardiovascular diseases during adolescence warrants significant attention from public health professionals. Previous research has highlighted the importance of environmental influences on health-related behaviors and outcomes, especially the socioeconomic environment (25–29). However, limited research has examined the relationship between indicators of neighborhood socioeconomic environment and components of physical fitness and/or physical activity among youth. The follow section aims to summarize existing literature and draw conclusions regarding the relationship between the socioeconomic environment and youth physical fitness and physical activity levels. Finally, gaps in the literature will be identified and used to inform recommendations for future research.

Neighborhood Socioeconomic Environment and Physical Fitness. Only one study examining the relationship between neighborhood socioeconomic environment and components of physical fitness was identified. While the results suggest an association between the socioeconomic environment and components of fitness, the strongest relationship was observed with cardiorespiratory fitness (58). These findings suggest that youth cardiorespiratory fitness may be more strongly associated with neighborhood socioeconomic factors than body composition or weight status. However, the referenced study aggregated data to the school-level and did not control for individual-level factors. Given that cardiorespiratory fitness is a powerful marker of health and limited research has examined the influence of neighborhood socioeconomic environment on fitness, additional research is needed. Future studies should employ multilevel and/or spatial modeling techniques to account for individual-level factors and clustering of youth in schools and neighborhoods.

Neighborhood Socioeconomic Environment and Weight-Related Outcomes. In general, findings from existing literature support a relationship between indicators of neighborhood socioeconomic environment and weight-related outcomes in youth. More specifically, neighborhoods characterized by less favorable socioeconomic environments were typically associated with higher BMI and/or prevalence of obesity among youth. Additionally, indicators of neighborhood socioeconomic environment were reported to explain a substantial portion of the observed disparities in body composition and/or weight status across race/ethnicity groups. Such evidence suggests that neighborhood socioeconomic deprivation may be a contributing factor to race/ethnicity differences in youth weight-related outcomes.

Across studies that examined the joint effect of neighborhood socioeconomic and built environment characteristics, a majority reported that both were associated with weight-related outcomes among youth. However, factors of the neighborhood socioeconomic environment tended to be stronger predictors of weight-related outcomes compared to built environment characteristics. Among studies that controlled for physical activity, the results were inconsistent. In one study, self-reported physical activity and indicators of neighborhood socioeconomic environment were both associated with weight status (180). In another study, the addition of physical activity and cardiorespiratory fitness into the model completely eliminated and significantly reduced the association of neighborhood socioeconomic environment with body mass and waist circumference, respectively (186). The results from these two studies suggest that youth from more deprived neighborhoods are less active, which could contribute to the observed disparities in obesity. However, a third study reported that physical activity did not attenuate the relationship between neighborhood socioeconomic environment and weight status, which led the authors to conclude that an alternate pathway might better explain the observed association (183).

Some studies noted differences in the association between neighborhood socioeconomic environment and weight-related outcomes across sociodemographic subgroups. Conflicting evidence was found when examining the influence of neighborhood socioeconomic environment on weight-related outcomes by sex. Specifically, one study reported the influence of neighborhood socioeconomic environment on weight status to be greater among girls (121), while another reported a stronger association among boys (187). Concerning socioeconomic status, evidence suggests that neighborhood socioeconomic deprivation adversely impacts weight status among youth living above the poverty threshold. However, neighborhood socioeconomic deprivation was not associated with weight status among youth living below the poverty threshold (185). This evidence suggests that the adverse effect of living in a socioeconomically deprived neighborhood may have a stronger impact on youth living above the poverty threshold whose families have greater access to resources.

Only two studies reported no association between neighborhood socioeconomic status and body composition/weight status. One examined a younger age group and reported that home and parent factors were associated with weight status, while neighborhood socioeconomic and built environment factors were not related (188). These results support previous findings that showed a stronger association between neighborhood factors and health outcomes among adolescents compared to younger children (120, 121). The second study was the only study to examine characteristics of the social environment in conjunction with characteristics of the socioeconomic and built environment (150). Given the similar nature of the two constructs, it is possible that measures of neighborhood social and socioeconomic environments were correlated; which could have produced biased estimates and contributed to the null association.

Neighborhood Socioeconomic Environment and Physical Activity. Studies examining the relationship between neighborhood socioeconomic environment and physical activity were inconsistent with approximately half reporting a significant relationship between indicators of neighborhood socioeconomic environment and physical activity among adolescents. Most were cross-sectional in design and used subjective and/or crude measures of physical activity. Studies reporting a significant association were more likely to use a composite index to measure neighborhood socioeconomic environment; whereas studies using independent variables to measure neighborhood socioeconomic environment were more likely to report null associations. Among studies examining the built environment in conjunction with indicators of the neighborhood socioeconomic environment, the neighborhood socioeconomic environment was more often associated with activity levels than features of the built environment. Given these findings, the neighborhood socioeconomic environment may have a greater influence on activity levels than the built environment. Notably, however, the results from two studies suggest that youth residing in neighborhoods characterized by poor socioeconomic environments may be more likely engage in physical activity when supportive built environments are present.

Gaps and Future Directions.

In reviewing existing studies, several limitations and gaps in the literature emerge. This section briefly summarizes the identified gaps in the literature and offers suggestions for future research. Lastly, the literature review concludes by identifying the gaps in the literature that proposed dissertation aims to address and then introducing the conceptual model that was used to guide the development of the dissertation aims.

Socioecological Approach. Previous research has noted that the simultaneous consideration of neighborhood socioeconomic environment, built environment, and individual-level characteristics is important in understanding how the neighborhood context influences health outcomes and health-related behaviors (149, 172). Some researchers have noted that failure to account for both the neighborhood socioeconomic and built environment could result in biased estimates and an inaccurate depiction of the environment-health relationship (172). However, few studies have examined the synergistic effect of neighborhood socioeconomic and built environments on youth cardiorespiratory fitness and physical activity (7).

Study Population. A limited number of studies have examined the influence of neighborhood socioeconomic environment on adolescent health outcomes and/or associated risk factors; particularly cardiorespiratory fitness and physical activity levels. To date, a majority of studies have focused largely on the influence of neighborhood socioeconomic status on broader health outcomes in adult populations (149). Given that adolescence is a crucial development stage in which widening health inequalities have been documented, public health professionals should prioritize 1.) the promotion of health enhancing behaviors and 2.) the identification of modifiable drivers of health inequalities among adolescents.

Study Methodology and Measures. Limited research examining the association between cardiorespiratory fitness, physical activity, and neighborhood socioeconomic environment among adolescents was identified. Across existing studies, there was considerable variability in methodology and measures employed. This variability may, in part, explain the observed inconsistencies in the literature.

Study Design. A majority of studies employed a cross-sectional study design. Only five studies examined change in the outcome variable over time; four measured weight-related outcomes and one measured self-reported physical activity. Thus, it is difficult to assess the potential causal relationship between the neighborhood socioeconomic environment and individual-level outcomes. More longitudinal studies are needed to better determine the influence of the neighborhood socioeconomic environment across the lifespan.

Outcome Measures. Concerning physical fitness, a majority of the studies examined the relationship between neighborhood socioeconomic environment and only one fitness component (i.e., body composition, weight status). One study examined the relationship between indicators of the neighborhood socioeconomic environment and multiple components of physical fitness using data aggregated to the school-level. Additional studies employing multilevel methods are needed to further examine this relationship. A primary limitation of studies examining the relationship between neighborhood socioeconomic environment and physical activity was the use of subjective measures of activity. Across those studies, measures of physical activity were inconsistent and crude. Only two studies objectively measured physical activity using accelerometry. Given the dearth of research examining the relationship of neighborhood socioeconomic environment with cardiorespiratory fitness and objective measures of physical activity, additional high-quality studies are needed to provide important information and fill gaps the literature.

Neighborhood Socioeconomic Environment. The measures used to assess neighborhood socioeconomic environment varied considerably with no studies employing the same measure or methodology. Current literature supports the use of a composite index measure of the neighborhood socioeconomic environment in order to accurately capture differences in small geographic areas (151). However, only half of the identified studies used a composite measure of neighborhood socioeconomic environment. The remaining studies used single variables as a measure of neighborhood socioeconomic environment. In general, most of studies used census tracts or an equivalent area-level measure as the geographic unit to assess neighborhood socioeconomic environment. Lian and colleagues noted that the composite neighborhood socioeconomic index score was similar at census tract and block group levels, but differed at the county level. A more standardized approach to developing and operationalizing the neighborhood socioeconomic environment will help to synthesize results and draw conclusions across studies. As such, future studies should use current recommendations to construct a composite measure of neighborhood socioeconomic environment that is appropriate for the study area of interest (151).

Multilevel and Spatial Analytic Techniques. While a majority of studies did use multilevel modeling techniques to examine neighborhood effects on individual health outcomes and behaviors, very limited research has employed spatial analytic techniques to account for clustering of data and/or spatial proximity of participants. Failure to account for spatial autocorrelation between individual-level measures may produce biased estimates that underestimate the effect of neighborhood factors on health.

The proposed dissertation will address some of these gaps in the literature and examine potential mechanisms driving the geographic distribution of adolescent health outcomes and health-related behaviors; specifically, cardiorespiratory fitness and physical activity levels.

Study Methodologies

The purpose of this dissertation is to describe how characteristics of neighborhood socioeconomic environment and elements of the built environment are associated with cardiorespiratory fitness and physical activity in three diverse samples of adolescents. To accomplish this goal, the proposed dissertation will utilize three existing data sources that contain measures of adolescent cardiorespiratory fitness and/or physical activity levels. Each dataset will be combined with publicly available census data to address the research aims. Based on the literature review, it is hypothesized that the neighborhood socioeconomic environment will be associated with cardiorespiratory fitness and physical activity levels in adolescents. More specifically, adolescents residing in neighborhoods characterized by poor socioeconomic environments (i.e., areas of concentrated deprivation) will exhibit lower physical activity and cardiorespiratory fitness levels. Building from the review of the literature, the remainder of this section introduces the conceptual model that guided the development of the research aims and objectives, identifies gaps in the literature that the proposed dissertation will address, and describes the study methodology that is proposed to address each aim of the dissertation.

Conceptual Model. To guide the development of the aims and objectives for this dissertation, a conceptual model was developed to depict proposed pathways that may explain the relationship between neighborhood socioeconomic environment, physical activity, and cardiorespiratory fitness in adolescents (Figure 6.1). The development of the conceptual model was influenced heavily by previous literature and the three ecological models described in the literature review. The conceptual model depicts the importance of examining the independent influence of the socioeconomic environment on health as well as its influence on other neighborhood- and individual-level characteristics that are known to influence health-related behaviors and outcomes.

The proposed conceptual model identifies potential mechanisms driving the geographic distribution of adolescent health outcomes; specifically, cardiorespiratory fitness levels. As depicted in the model, neighborhood socioeconomic environment is hypothesized to exert both a direct and indirect influence on cardiorespiratory fitness. For instance, contextual factors of the neighborhood socioeconomic environment may directly influence cardiorespiratory fitness levels among adolescents (e.g., physiological responses to environment stimuli). Alternatively, characteristics of the neighborhood physical activity environment and/or physical activity behaviors may mediate the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness level in adolescents. Finally, the relationship between neighborhood socioeconomic environment, physical activity, and cardiorespiratory fitness could vary across individual-level characteristics (i.e., moderators).

Gaps Addressed by the Proposed Dissertation. Guided by this conceptual model, the proposed dissertation aims to address some of the identified gaps in the literature and contribute to the limited body of research that has examined the relationship between the socioeconomic environment and cardiorespiratory fitness among adolescents. Overall, the proposed dissertation will utilize stronger measures, study designs, and/or analytic approaches to address existing gaps in the literature. With respect to the research aims, each will address specific gaps identified in the literature review.

Aim 1, which will utilize data from the South Carolina FITNESSGRAM project, will be the first study to examine the relationship between characteristics of the socioeconomic environment and cardiorespiratory fitness levels in adolescents using a multilevel modeling approach controlling for individual sociodemographic characteristics. Building on the first aim, Aim 2 will be the first study to utilize a nationally representative sample of adolescents to examine the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness. Further, this study will be the first to examine the potential mediating role of physical activity on this relationship. If physical activity is found to mediate the relationship, the promotion of physical activity among adolescents living in neighborhoods characterized by poorer socioeconomic environments could be an effective strategy to mitigate the negative impact of the socioeconomic environment on fitness levels.

Lastly, Aim 3 will also address several gaps identified in existing literature. This study will be the first to examine the influence of the neighborhood socioeconomic environment on objectively measured physical activity levels over time. The use of an objective measure of physical activity will provide a more accurate assessment of adolescent activity levels and addresses an important limitation of previous research. The longitudinal study design will allow researcher to better assess the potential causal relationship between the neighborhood socioeconomic environment and physical activity. Additionally, the use of a multilevel spatial modeling technique and inclusion of a built environment measure in the model will provide a more accurate assessment of the relationship between the neighborhood socioeconomic environment and physical activity levels among adolescents. Finally, this dissertation will use current recommendation in the literature to construct a composite index measure of area-level socioeconomic environment. The following section provides a brief overview of how neighborhood socioeconomic environment will be measured and identifies strengths and limitation of the proposed measurement approach.

Neighborhood Socioeconomic Environment. Neighborhood socioeconomic environment will be the primary exposure variable for each aim in the proposed dissertation. To date, there is considerable variability in the measurement of the socioeconomic environment. However, recent recommendations call for the construction of an index score to measure contextual factors of the broader socioeconomic environment (151, 152). The use of a composite index score to measure the socioeconomic environment has several strengths. For instance, an index score allows researchers to capture multiple attributes of small geographic areas and produces a more accurate measure of the socioeconomic environment than individual variables (151).

Data Source. To measure the socioeconomic environment, publicly available data will be obtained from the American Community Survey (ACS; www.census.gov/programs-surveys/acs/). The ACS is a continuous survey that is conducted by the U.S. Census Bureau to collect population-level data on income, family composition, and other related household and individual characteristics. The information collected by the ACS was originally collected every 10 years via the long form of the decennial population census. However, in 2005, the ACS took the place of the long form sample of the decennial census of the U.S. population. Following the introduction of the ACS, the decennial population survey now uses only the short form which collects the following characteristics: age, sex, race, ethnicity, relationship to householder, and owner/renter status. The goal of the ACS is to produce more timely population estimates that are similar in precision to the long form sampling approach of the decennial census. Each month, the ACS selects nearly 300,000 housing units from which to collect information; roughly 3.5 million households annually. Selected households receive a questionnaire in the mail and follow up telephone call if necessary. Response rates are high with over 95% of selected households typically completing the survey each year (191, 192).

Estimates. The ACS produces period estimates that are designed to represent population and housing characteristics of a geographic area during a specified timeframe. Given the continuous nature in which the data is collected, ACS data for smaller geographic areas must be compiled over time to produce more accurate and reliable estimates of population characteristics. The ACS produced estimates in 1-year, 3-year, and 5-year increments. The 1-year estimates represent 12 months of collected data and are recommended for geographic areas with a population greater than 65,000 individuals. The 3-year estimates represent 36 months of collected data and are recommended for areas with populations greater than 20,000 people. Finally, the 5-year estimates represent 60 months of collected data and are recommended for all geographic area, especially those less than 20,000 individuals (191, 192).

Geographic Unit. The ACS provides population estimates for geographic areas of varying sizes including national, state, zip code area, county, school districts, census tract, and block group (191, 192). For the proposed study, census tract will be the geographic unit of analysis. A census tract is a contiguous geographic area whose size is determined by population density. The optimal population size for a census tract is 4,000 people; however, the population can range from 1,200 and 8,000 people. Census tract are designed to: 1) be homogenous with respect to population characteristics, economic status, and living conditions; and 2) have boundaries that follow visible and identifiable features that are intended to be maintained over time for comparison purposes. Also, census tracts can vary significantly in spatial area depending on population density (e.g. urban vs. rural) (192). Given their smaller population size, ACS recommends that data for census tracts be represented by 5-year estimates only (191). Previous research has shown composite neighborhood socioeconomic environment index score is similar at census tract and block group levels but differs when larger geographic units such as counties are used. This is likely due to increased heterogeneity in population characteristics across larger geographic units (151).

Measurement. To calculate the socioeconomic environment index, data for the census tracts corresponding to the study region of interest will be selected. Specifically, 20 census tract variables across 6 domains will be obtained for all census tracts in the study region. Principle component analysis with varimax rotation will then be used to examine the data structure of the census tract variables. The common factor accounting for the largest proportion of the total variance will be selected. Next, selected variables will be standardized and weighted based on their corresponding factor score coefficient from the principle component analysis. Finally, a composite index score will be constructed by summing these values. For ease of interpretation, index scores may also be expressed as quartiles. The methods proposed to construct the index are consistent with current recommendations in the existing literature (151).

Study One Methodology

Background. Cardiorespiratory fitness is a powerful marker of health. However, limited research has examined the influence of indicators of the socioeconomic environment on fitness among adolescents. The first aim of this dissertation will address this gap in the literature and employ multilevel modeling with a spatial extension to account for individual-level factors and clustering of youth within schools.

Purpose. The purpose of this study is to examine the relationship between cardiorespiratory fitness and contextual factors of the socioeconomic environment in a diverse sample of school-aged youth using multilevel spatial analytic techniques. The aim of this study will be addressed using two objectives. In the first objective (Objective 1A), we will evaluate the independent association between the socioeconomic environment and cardiorespiratory fitness among adolescents. The second objective (Objective 1B) will determine if student sociodemographic characteristics moderate the relationship between the socioeconomic environment and cardiorespiratory fitness levels.

Aim 1: To describe the association between socioeconomic environment and cardiorespiratory fitness levels in a diverse sample of students.

Objective 1A: To describe the association between the socioeconomic environment and cardiorespiratory fitness levels.

Objective 1B: To determine if the association between the socioeconomic environment and cardiorespiratory fitness varies across age, sex, race/ethnicity, and socioeconomic subgroups.

Methods.

Data Source & Study Design. Data from the South Carolina Department of Health and Environmental Control's (SC DHEC) FITNESSGRAM project will be utilized to address Aim 1. The SC DHEC FITNESSGRAM project is a state-wide observational study to evaluate and ultimately improve health-related fitness among approximately 740,000 public school students in South Carolina. Its primary purpose is to capture health-related fitness data from public schools across the state. The findings from this project will be used to support planning and implementation of evidence-based programs and policies to improve health-related fitness. To address Aim1, student-level data for school year 2015-2016 (August 2015 through June 2016) will be utilized.

Sampling & Study Population. All South Carolina public schools serving grades K-12 were eligible to participate in the FITNESSGRAM project. Each school was asked to conduct fitness testing and record health-related fitness data for students enrolled in physical education class. During school year 2015-2016, approximately 630 (51%) public schools across 49 (48%) school districts participated in the SC DHEC FITNESSGRAM project (193). For the purpose of this study, the sample will be restricted to students in grades 5, 8, and 9-12 attending public school in South Carolina. FITNESSGRAM data was received for approximately 80,000 public school students for school year 2015-2016.

Data Collection & Management. In participating schools, the FITNESSGRAM was administered by school staff (e.g., physical education teacher) during physical education class. Prior to administration of the FITNESSGRAM, school staff received training support through the President's Youth Fitness Program. Staff reported students' performance on the FITNESSGRAM components using a web-based version of the FITNESSGRAM software. All data were submitted to the SC DHEC. The University of South Carolina received de-identified student data from the SC DHEC to assess health-related fitness among South Carolina students.

Outcome Variable: Cardiorespiratory Fitness. The FITNESSGRAM is an assessment of five components of health-related fitness: aerobic capacity (i.e. cardiorespiratory fitness), strength, endurance, flexibility, and body composition. To address Aim 1, cardiorespiratory fitness will act as the primary outcome variable of interest. Cardiorespiratory fitness was measured using one of three field assessments: Progressive Aerobic Cardiovascular Endurance Run (PACER) test, a 1-mile run test, or a walk test. A majority of students participated in the PACER test to assess cardiorespiratory fitness levels. The PACER is a multistage, progressive fitness test that involves participants running at a specified pace for as long as possible. The PACER is scored based on the number of laps completed; a lap is equal to one 20-meter distance. Cardiorespiratory fitness is estimated by the FITNESSGRAM software using the number of PACER laps completed in addition to a student's age and sex. For the one-mile run/walk test, time to completion, age, sex, height, and weight are used to estimate fitness level. Cardiorespiratory fitness is reported as estimated VO_2max and expressed as $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. High test-retest reliability and validity have been demonstrated for each field assessment test of cardiorespiratory fitness. Additional information regarding the administration of the cardiorespiratory fitness field tests and the calculation of cardiorespiratory fitness are available in the FITNESSGRAM manual (194).

For analysis purposes, cardiorespiratory fitness will be expressed as both a continuous and categorical variable. Estimated VO_2max will be a continuous variable indicating a student's cardiorespiratory fitness level. The FITNESSGRAM software also provides health-related standards to evaluate cardiorespiratory fitness level. The standards are age and sex specific and account for developmental changes in fitness due to growth and maturation. The standards classify fitness into one of three health zones: 1) Healthy Fitness Zone; 2) Needs Improvement; and 3) Needs Improvement – Health Risk. Students meeting the minimum threshold for Healthy Fitness Zone are classified as having a sufficient level of fitness for good health and are provided with feedback on how to maintain fitness. Students with a cardiorespiratory fitness level below this threshold are classified into one of the two improvement categories and are advised accordingly.

Exposure Variable: Socioeconomic Environment. The socioeconomic environment will be the primary exposure variable to address Aim 1. Socioeconomic environment will be expressed as a composite index score at the census tract level. The index score will be calculated using the methodology described in the previous section. Data will be obtained from American Community Survey (ACS) 5-year estimates for 2011-2015. For ease of interpretation, the socioeconomic environment index scores may also be expressed as a categorical variable (e.g., quartiles).

Since student's neighborhood of residence (i.e., census tract) could not be determined in the current dataset, school census tract and the surrounding census tracts will be used as a proxy measure for the socioeconomic environment. While not a perfect proxy for neighborhood socioeconomic environment, the researchers believe this approach is an acceptable solution given previous research examining the distribution of socioeconomic status across U.S. public schools and neighborhoods (195). Student enrollment in a given school is often determined by the neighborhood in which the family resides. In most instances, students are designated to attend the school in closest proximity to their home of residence. Thus, the immediate and surrounding socioeconomic environment of the school is likely to represent the socioeconomic environment of students attending that school.

Moderating Variables: Student Characteristics. The potential moderating effect of age, sex, race/ethnicity, and socioeconomic status on the relationship between cardiorespiratory fitness and socioeconomic environment will be examined to address Objective 1B. Student sociodemographic characteristics were reported by school staff via the FITNESSGRAM software or were provided by the SC DHEC. Age was reported in number of years and expressed as a continuous variable. Sex was reported as male or female. Race was reported in the following groups: American Indian, Asian, Black or African American, Hawaiian or Pacific Islander, White, or Other. Ethnicity was determined by whether individuals reported Hispanic or Latino origin. For analyses, race and ethnicity groups will be collapsed into the following categories: Non-Hispanic White, Non-Hispanic Black, Hispanic or Latino, and Other (including multiracial). Socioeconomic status was assessed using a student's free/reduced lunch status on the 135 day of the school year as a proxy measure for student/family socioeconomic status (dichotomous variable).

Covariate: Body Mass Index (BMI). Based on existing literature, body composition may be a potential covariate. Body composition is one of five components of health-related fitness captured by the FITNESSGRAM and was assessed using BMI. To determine BMI, trained school staff objectively measured height and weight. BMI was calculated using the following standard equation: BMI = weight (kg) / height (m^2). For youth, BMI is typically reported as a percentile (range: 0-100) relative to other adolescents of the same sex and age. For ease of interpretation, percentiles will be categorized into weight status categories using CDC growth charts: underweight ($<5^{th}$ percentile), normal weight (5^{th} percentile to $<85^{th}$ percentile), overweight (85^{th} percentile to $<95^{th}$ percentile), and obese ($\geq 95^{th}$ percentile) (196).

Statistical Analyses.

To describe the relationship between the socioeconomic environment and cardiorespiratory fitness, a multilevel linear regression (continuous CRF) and multilevel logistic regression (categorical HFZ) framework will be applied with a spatial analysis extension. Specifically, Conditional Autoregressive Regression (CAR), a spatial analysis extension to traditional random effects models, will be used to incorporate information from census tracts adjacent to school census tracts. The proposed analytic approach will enable the researchers to examine the association of individual-level and area-level predictors with cardiorespiratory fitness while simultaneously accounting for non-independence of the observations (197).

Applying a spatial extension to the traditional regression modeling approach to address Aim 1 has several advantages. First, the spatial model will incorporate information from census tracts surrounding each school. This will allow for area-based parameter estimates to be influence by a group of neighbors and helps to account for border issues resulting from census tract boundary lines. Additionally, this approach will allow researchers to use the spatial area around a school as a proxy for neighborhood socioeconomic environment since this information is not available. In summary, applying a spatial analytic approach can incorporate information about the census tracts surrounding the school and will allow for a more accurate estimate of the socioeconomic environment's influence on cardiorespiratory fitness.

Objective 1A Model Building. To address Objective 1A, multilevel linear and multilevel logistic regression analyses will be employed. In the multiple linear regression analyses, cardiorespiratory fitness will be expressed as a continuous variable. In the multilevel logistic regression analyses, cardiorespiratory fitness will be expressed as a categorical variable with two levels: *Healthy Fitness Zone* and *Needs Improvement*. All analyses will account for the hierarchical structure of the data with students nested within schools. Level 1 variables include the individual-level characteristics age (years), sex (two levels: male [referent] and female), race/ethnicity (four levels: Non-Hispanic White [referent], Non-Hispanic Black, Hispanic or Latino, and Other), free/reduced lunch status (two levels: yes and no [referent]), and weight status (three levels: underweight/normal [referent], overweight, and obese). Level 2 variables include census tract socioeconomic environment index score. The expression of each variable will be the same for all analyses.

Prior to building statistical models, the criterion used to identify and weight neighboring census tracts must be established. We will employ a first-order neighbor structure using queen-based contiguity approach to identify census tracts neighboring one another. This is the most common approach to defining neighbors in spatial analysis. The term derives from the game of chess where the queen can move in any direction and implies that any two census tracts sharing a border in any direction will be considered neighbors (198). After selecting a neighbor structure, a spatial weights matrix based on binary connectivity will be developed. Using this weighting approach, neighboring census tracts will be coded as ‘1’ while census tracts that do not share a border (i.e., not identified as neighbors) will be coded as ‘0’ in the spatial weights matrix.

A series of regression models will be generated for each expression of the outcome variable. First, bivariate associations between each predictor variable (i.e. independent, moderating, and covariate variables) and both expressions of the cardiorespiratory fitness will be examined. Next, the following multilevel models will be produced to address Objective 1A: (1) empty multilevel model without any explanatory variables predicting cardiorespiratory fitness (Null Model); (2) single-level model including individual-level predictors (Level-1 Multilevel Model); (3) two-level model including individual and census tract variables (Level-2 Multilevel Model); (4) three-level spatial modeling including individual and census tract variables with a spatial extension to incorporate neighbor information (Spatial Model). The assumptions (i.e., independence, normality) of each statistical model will be assessed.

Objective 1B Model Building. Next, interaction terms will be introduced to the model from Objective 1A to examine the potential moderating effect of student age, sex, race/ethnicity, and socioeconomic status on the relationship between cardiorespiratory fitness and socioeconomic environment. First, an interaction terms for each individual-level characteristic and socioeconomic environment will be added to the model separately. Then significant interactions will be added to the full model. To maintain a parsimonious model, only interactions remaining significant in the full model will be retained. If an interaction terms is significant, estimate statements will be generated to examine the effect of socioeconomic environment on cardiorespiratory fitness across varying levels of student sociodemographics. For ease of interpretation of significant interactions, socioeconomic environment may also be examined as a categorical variable.

Finally, the amount of spatial variability in cardiorespiratory fitness explained by socioeconomic environment index score will be calculated from the final model.

Model Fit. Statistical significance and model fit will be examined for each model. Using maximum likelihood estimation methods, Akaike's Information Criterion (AIC) will be used to assess model fit. Lower values of AIC indicate better model fit. An alpha level less than 0.05 will denote statistical significance for two-sided statistical tests. For multilevel linear regression analyses, the mean regression coefficients (β) and their 95% confidence intervals will be estimated. For multilevel logistic regression analysis, odds ratios and the corresponding 95% confidence intervals will be reported. All analyses will be conducted in R software using the spdep, glm, and/or bugs functions.

If model convergence is an issue, Bayesian inference will be considered in place of maximum likelihood estimation methods. While estimation methods have been developed for multilevel and spatial models, a Bayesian approach tends to better handle complex hierarchical data structures. However, this method also introduces additional bias into the models due to estimation of priors. If Bayesian inference estimation methods are employed, models will be fit using Monte Carlo Markov Chain (MCMC) methods. Gibbs sampler will be used to estimate fixed and random effects and priors will be set to non-informative. Model fit will be assessed using the Deviance Information Criterion (DIC), with lower DIC values indicate better model fit.

Study Two Methodology

Background. Evidence suggests that the socioeconomic environment is independently associated with health across the lifespan. Among adults, existing literature has shown a consistent inverse relationship between neighborhood socioeconomic environment and multiple health outcomes including cardiovascular disease, mortality, and cardiorespiratory fitness (157, 161, 199). However, limited research has examined the influence of neighborhood socioeconomic environment on health and health-related behaviors during adolescence. During this developmental stage, cardiorespiratory fitness is already an important marker of health and a strong predictor of cardiovascular disease and all-cause mortality. To date, no previous study has examined the influence of the neighborhood socioeconomic environment on cardiorespiratory fitness and the potential mediating role of physical activity on this relationship.

Purpose. Given the established relationship between cardiorespiratory fitness and physical activity, the purpose of this aim is to determine whether physical activity mediates the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness in a nationally representative sample of adolescents. The aim of this study will be addressed using two objectives. In the first objective (Objective 2A), we will examine the independent association between neighborhood socioeconomic environment and cardiorespiratory fitness. The second objective (Objective 2B) will determine the potential mediating role of physical activity on the relationship between neighborhood socioeconomic status and cardiorespiratory fitness.

Aim 2: To describe the relationships among neighborhood socioeconomic environment, physical activity, and cardiorespiratory fitness levels in

a nationally representative sample of U.S. adolescents (12-15 years old).

Objective 2A: To describe the association between neighborhood socioeconomic environment and cardiorespiratory fitness in a nationally representative sample of U.S. adolescents.

Objective 2B: To determine if physical activity mediates the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness in a nationally representative sample of U.S. adolescents.

Methods.

Data Source & Study Design. Data from the 2012 NHANES National Youth Fitness Survey (NNYFS) will be utilized to address Aim 2. The NNYFS was conducted in conjunction with 2012 NHANES by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics (NCHS). The NNYFS was a 1-year survey that employed an observational study deign. The primary purpose of the survey was to collect information regarding physical activity and fitness levels in a nationally representative sample of non-institutionalized U.S. youth (3-15 years old). All protocols were approved by the NCHS Review Board. Each participant and a parent/guardian provided informed written consent prior to participation in the study. To address Aim 2, access to restricted geographic information will be required to link a measure of neighborhood socioeconomic environment with individual-level variables. In order to acquire this information, a research proposal must be submitted to and approved by CDC's Research Data Center.

Sampling & Study Population. The NNYFS survey design was based on NHANES, which uses a complex, stratified, multistage probably cluster sampling design. The NNYFS sample was selected from an independent sample of occupied housing units within the selected NHANES segments. Data was collected on a total of 1,576 children and adolescents. The NCHS recommends 6 to 11 year-old participants be categorized as children and 12 to 15 year old participants be categorized as adolescents. For the purpose of this proposal, only adolescents will be examined.

Data Collection & Management. Data collection consisted of two measurement components, a household interview and a physical examination. First, an interview was conducted by a trained research staff member in the adolescent's household. Then an assessment of physical fitness was conducted by trained staff in a Mobile Examination Center (MEC). The demographic, physical activity, and cardiorespiratory fitness data needed to address Aim 2 were collected during the household interview and mobile exam. This information is publicly available through the NCHS. However, access to restricted geographic information (i.e. participant's residential census tract) will be required to link individual-level data with a measure of neighborhood socioeconomic environment. Specifically, the census tract corresponding to each participant's home of residence is required to link publicly available data from the NNYFS (i.e., individual-level outcome, mediating, and covariate variables) with a measure of neighborhood socioeconomic environment.

Outcome Variable: Cardiorespiratory Fitness. To address Aim 2, cardiorespiratory fitness will act as the primary outcome variable of interest. Cardiorespiratory fitness was measured using a standard submaximal treadmill test. The test consisted of a 2-minute warm up phase, two 3-minute exercise phases, and a 2-minute recovery phase. Participants were assigned to one of five treadmill test protocols, which varied in terms of grade and speed. Each protocol was designed to elicit a heart rate that was approximately 75 percent of a participant's age-predicted maximal heart rate (220 minus age) by the end of the test. Trained staff determined the treadmill test protocol using participant's age, sex, BMI, and self-reported physical activity level. Heart rate was captured after each exercise stage of the test and used to estimate maximal oxygen consumption (i.e., VO_2max) achieved during the treadmill test. Estimated VO_2max was expressed as $ml \cdot kg^{-1} \cdot min^{-1}$. Level of cardiorespiratory fitness was then determined based on age- and sex-specific thresholds of estimated VO_2max. Based on standards established by the FITNESSGRAM program, participants were categorized into one of two fitness levels: 'Healthy Fitness Zone' and 'Needs Improvement'. Additional information regarding the administration of the submaximal treadmill test and the estimation of cardiorespiratory fitness are available in the NNYFS manual (200).

Exposure Variable: Neighborhood Socioeconomic Environment. The neighborhood socioeconomic environment will be the primary exposure variable in Aim 2. Neighborhood will be defined as a participant's census tract of residence. This variable is restricted by the NCHS and the researchers will not have direct access to this information. As such, the researchers will construct a measure of neighborhood socioeconomic environment for all census tracts in the contiguous United States (i.e., approximately 72,247 census tracts; representing the potential NHANES sampling frame). To construct a measure of neighborhood socioeconomic environment, data will be obtained from American Community Survey (ACS) 5-year estimates for 2011-2015 and an index score will be calculated using the methodology described at the beginning of the section. Due to restrictions imposed by the CDC's Research Data Center, the researchers will not be permitted to use the continuous expression of the exposure variable. In response to this restriction, neighborhood socioeconomic environment will be expressed as a categorical variable at the census tract level. The researchers will categorize the index score into deciles. Prior to analysis, NCHS will merge the researchers measure of neighborhood socioeconomic environment with NNYFS data using restricted geographic identifier information. The sample will be restricted to census tracts included in the NNYFS sample; the number of census tracts included is unknown. Depending on the distribution of the neighborhood socioeconomic environment deciles in the NNYFS sample, the categories may be collapsed into smaller groupings for analysis (e.g., quartiles).

Mediating Variable: Physical Activity. Physical activity was self-reported via a questionnaire administered during the household interview or the mobile examination. Trained interviewers asked an array of physical activity related questions using the Computer-Assisted Personal Interviewing (CAPI) system. Adolescents completed additional questions that were designed to capture time spent in moderate and vigorous physical activity across three settings (Recreation, Work, and Transportation). Using the

NNYFS suggested metabolic equivalent (MET) scores for these additional questions, physical activity time estimates will be converted into MET-minutes per week (201). Total weekly MET-minutes will be calculated by summing the estimated MET-minutes per week across the three settings. Physical activity will be expressed as average daily MET-minutes and calculated by dividing estimated total weekly MET-minutes by seven. For ease of interpretation, average daily MET-minutes may also be examined as a categorical variable (e.g., tertiles).

Covariates: Adolescent Characteristics. Based on existing literature, sociodemographic characteristics that will be considered as potential covariates in Aim 2 include age, sex, race/ethnicity, socioeconomic status, and body mass index (BMI). Age was calculated based on a participant's date of birth. The variable is reported as years of age at the time of data collection and expressed as a continuous variable. Gender was reported as male or female. Race/ethnicity will be reported in the following categories: Non-Hispanic White, Non-Hispanic Black, Mexican American/Hispanic, and Other (includes multi-racial). Socioeconomic status will be expressed as income-to-poverty ratio. To calculate the ratio, self-reported family income will be divided by a poverty measure in accordance with established poverty guidelines from 2012 Department of Health and Human Services. Finally, BMI will be expressed as weight in kilograms divided by height in meters squared (kg/m^2). Height and weight were measured by trained research staff during the mobile examination using a stadiometer SECA 217 and a portable scale SECA 869, respectively. Using BMI, weight status was classified into four categories based on age- and sex-specific percentiles from 2000 CDC growth charts (underweight: <5th percentile; normal weight: 5th percentile to <85th percentile; overweight: 85th percentile to <95th percentile; obese: ≥95th percentile).

Statistical Analyses.

To examine the relationship between neighborhood socioeconomic environment, physical activity, and cardiorespiratory fitness, a multiple linear regression and multiple logistic regression framework will be applied. Cardiorespiratory fitness will be expressed as a continuous variable in the multiple linear regression analyses. In the multiple logic regression analyses, cardiorespiratory fitness will be expressed as a categorical variable with two levels: Healthy Fitness Zone and Needs Improvement. Neighborhood socioeconomic environment, the primary exposure variable, will be expressed as a categorical variable. Physical activity will be expressed as average MET-minutes per day. Individual-level covariates will include age (years), sex (two levels: male [referent] and female), race/ethnicity (four levels: Non-Hispanic White [referent], Non-Hispanic Black, Mexican American/Hispanic, and Other), socioeconomic status, and weight status (three levels: underweight/normal [referent], overweight, and obese). Sample weights will be used in all analyses to account for the complex sampling design employed by the NNYFS. Weights were generated by the NCHS to account for the study design (e.g., selection probabilities, non-response) and allow for inferences to be made at the population level.

Objective 2A Model Building. All statistical analyses will be conducted in the following stages for both expressions of the outcome variable. First, descriptive statistics and bivariate associations between each predictor variable (i.e. independent, mediating, and covariate variables) and both expressions of the cardiorespiratory fitness will be examined. Then, a series of regression models will be generated for each expression of the outcome variable. To address Objective 2A, the crude association between cardiorespiratory fitness and neighborhood socioeconomic environment will be examined first. Adolescent characteristics will then be added to the model to determine the association between neighborhood socioeconomic environment and cardiorespiratory fitness after controlling for individual-level covariates. The assumptions (i.e., independence, normality) of each statistical model will be assessed.

Objective 2B Model Building. To determine the potential mediating role of physical activity on the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness, a series of regression models will be generated. First, the effect of neighborhood socioeconomic environment on cardiorespiratory fitness will be examined. Second, the relationship between neighborhood socioeconomic environment and physical activity will be examined. Third, the influence of neighborhood socioeconomic environment and physical activity on cardiorespiratory fitness will be examined. Physical activity will be considered a significantly mediator on the relationship between neighborhood socioeconomic environment and cardiorespiratory fitness if the impact of neighborhood socioeconomic environment is significantly reduced after controlling for physical activity. Lastly, adolescent covariates will be added to the model to examine these relationships in a fully adjusted model. If mediation is present, the physical activity variable may be examined as categorical variable for ease of interpretation. The assumptions (i.e., independence, normality) of each statistical model will be assessed.

Model Fit. Data access will be provided remotely through the NCHS RDC via their ANDRE remote access platform. All analyses must be conducted within the ANDRE platform on a secure computer using in SAS and/or SAS-callable SUDAAN software. The following procedures will be used to account for weighted data: PROC SURVEYREG and SURVEYLOGISTIC. Results are sent directly to the RDC for review and then shared with the researcher once approved. Due to the limitation of the ANDRE platform and SAS, applying a spatial analysis extension will not be possible. For multilevel linear regression analyses, the mean regression coefficients (β) and their 95% confidence intervals will be estimated. For multilevel logistic regression analysis, odds ratios and the corresponding 95% confidence intervals will be reported. Statistical significance and model fit will be examined for each model. Specifically, model fit will be assessed using Akaike's Information Criterion (AIC) with lower values indicating better model fit. An alpha level less than 0.05 will denote statistical significance for all analyses.

Study Three Methodology

Background. A growing body of evidence has consistently reported a positive association between neighborhood socioeconomic environment and health-related behaviors and outcomes. However, limited research has examined the influence of neighborhood socioeconomic environment on health-related behaviors among younger populations. Specifically, few studies have examined the association between neighborhood socioeconomic environment and physical activity among adolescents. Findings across existing studies are inconsistent with approximately half reporting a significant relationship. Most of the identified studies employed cross-sectional research designs and used subjective and/or crude physical activity measures. Despite the noted limitations, evidence suggests that the neighborhood socioeconomic environment may have a greater influence on physical activity than the built environment.

Purpose. The purpose of this study is to examine potential clustering of physical activity within neighborhoods and the extent to which characteristics of the neighborhood socioeconomic and built environment explain differences in activity levels as youth transition into adolescence. This aim will be achieved through three objectives. The first objective (Objective 3A) will describe the distribution of physical activity levels across neighborhoods within the study region. The second objective (Objective 3B) will determine the extent to which neighborhood socioeconomic environment explains the distribution of physical activity levels across neighborhoods over time. Finally, the third objective (Objective 3C) will determine if elements of the build environment moderate the relationship between the neighborhood socioeconomic environment and changes in physical activity as youth transition from childhood to adolescence.

Aim 3: To describe the longitudinal associations of neighborhood socioeconomic environment and elements of the built environment with physical activity in youth during the transition from childhood to adolescence.

Objective 3A: To determine if physical activity is spatially clustered within neighborhoods as youth transition from childhood to adolescence.

Objective 3B: To determine if neighborhood socioeconomic environment is associated with changes in physical activity as youth transition from childhood to adolescence.

Objective 3C: To determine whether elements of the built environment moderate the relationship between neighborhood socioeconomic environment and changes in physical activity as youth transition from childhood to adolescence.

Methods.

Data Source & Study Design. Data from the Transitions and Activity Changes in Kids (TRACK) study will be utilized to address Aim 3 of this dissertation. The TRACK study is a multi-level, longitudinal study designed to examine the factors that influence changes in physical activity as youth transition from elementary to middle school. The study employed a prospective cohort study design. Prior to participation in the study, written parental consent and child assent were obtained. This study was approved by the University of South Carolina's Institutional Review Board. To address Aim 3, cohort data from elementary (grade 5) and middle school (grade 7) will be utilized.

Sampling & Study Population. In 2010, two school districts in South Carolina agreed to participate in the study. Of the 24 elementary schools invited to participate, 21 agreed to take part in the study. Fifth grade students from participating schools were recruited through recruitment assemblies. A total of 1,080 5th graders (501 boys, 579 girls) were enrolled into the TRACK study at baseline. The sample was diverse with a self-reported race/ethnicity breakdown of 36.4% white, 35.1% black, 11.2% Hispanic, and 17.3% other races/ethnicities (including multi-racial). Participants were followed into middle school. Follow-up assessments were conducted during 6th and 7^{thh} grade. For the present study, only students that were measured at baseline (5th grade) and in the 7th grade will be included.

Data Collection & Management. At each year of data collection, data was collected across two measurement sessions. During the first session, each student completed a questionnaire, had anthropometric measurements taken, and received an accelerometer along with verbal and written instructions for wear. Approximately one week later, participants returned the accelerometer and received a participation incentive during the second measurement session. Trained measurement staff collected data during school in small groups (≤24 students) at a time and location determined by the school administration. All neighborhood and environment information was collected between the 5th and 6th grade school year.

Outcome Variable: Physical Activity. Physical activity was measured objectively using accelerometers (ActiGraph GT1M and GT3X models, Pensacola, FL). Previous research has validated the Actigraph accelerometer in youth and has also demonstrated that the devices has strong intra- and inter-instrument reliability and acceptable correlations with energy expenditure (202–204). Each participant was instructed to wear the accelerometer on their right hip during waking hours for seven consecutive days, except while bathing, swimming, or sleeping. Accelerometers were initialized to begin collecting data at 5:00 a.m. on the morning following distribution of the monitor. Data was collected and stored in 60-second epochs. Non-wear time was defined as any period of 60 minutes or more with consecutive zero activity counts. All periods defined as non-wear time were set to missing. Data from Sunday was excluded from the analytic dataset due to a minimal amount of data being recorded. Missing values for participants that provided at least two days with eight hours of accelerometer wear time were imputed using a sex-specific multiple imputation method via PROC MI in SAS (SM 14). Activity levels were determined by age-specific thresholds applied to accelerometer count data to distinguish between sedentary (0-100 counts per minute), light (100-2199 counts per minute), moderate (2200-5099 counts per minute), and vigorous (>5100 counts per minute) levels of physical activity. To address Aim 3, physical activity will be a continuous variable expressed as total physical activity and moderate-to-vigorous physical activity. Total physical activity will be defined as ≥ 100 counts per minute and includes light, moderate and vigorous physical activity. Moderate-to-vigorous physical activity will be defined as ≥2200 counts per minute and includes moderate and vigorous physical activity. Both total day physical activity and non-school physical activity will be examined.

Exposure Variable: Neighborhood Socioeconomic Environment. The neighborhood socioeconomic environment will be the primary exposure variable used to address Aim 3. In this study, neighborhood will be defined as a participant's census tract of residence. Neighborhood socioeconomic environment will be expressed as a composite index score at the census tract level. Data was obtained from American Community Survey (ACS) 5-year estimates for 2006-2010. Additional details regarding the calculation of the index score for neighborhood socioeconomic environment is provided at the beginning of this section.

Exposure Variable: Neighborhood Built Environment. The neighborhood built environment will also be examined as an exposure variable to address Aim 3. The TRACK study used the Physical Activity Resource Assessment (PARA) to collect information regarding features of the built environment that have been shown to influence youth physical activity behaviors (205). Specifically, the PARA was used to capture information regarding features (e.g. baseball field), amenities (e.g. drinking fountains) and incivilities (e.g., graffiti) of facilities that provide physical activity opportunities and resources. Within each community, trained data collectors identified facilities (i.e., churches, commercial facilities, trails, parks, and schools), confirmed offerings, and completed a PARA for each operational facility. A PARA index score was then calculated for each facility by summing up to 18 features and then subtracting the number of incivilities present (range 0 to 7). For each census tract in the study region, a score will be created by summing the PARA Index scores within the tract using GIS software (ArcGIS 10.1).

Covariates: Demographics. Based on existing literature, sociodemographic characteristics that will be considered as potential covariates in Aim 3 include age, sex, race/ethnicity, parent education, and body mass index (BMI). Participants reported their age, sex, and race/ethnicity on the student survey. Age was reported as years of age at the time of data collection and expressed as a continuous variable. Gender was reported as male or female. For race, participants were instructed to select each race category that applied (i.e., American Indian or Alaskan Native, Asian, Black or African American, Native Hawaiian or other Pacific Islander, White, or Other). For ethnicity, participants were asked to indicate whether they were of Hispanic or Latino origin. For analyses, race and ethnicity groups will be collapsed into the following categories: Non-Hispanic White, Non-Hispanic Black, Hispanic, and Other. As part of the parent survey, a parent or guardian was asked to report their highest level of education. For the present analyses, parent education will be used as a proxy measure for student/family socioeconomic status. Finally, BMI will be expressed as weight in kilograms divided by height in meters squared (kg/m^2). Height and weight were measured by trained data collectors. Standing and seated height were measured to the nearest 0.1 cm using a portable stadiometer (SECA, Hamburg Germany). Weight was measured to the nearest 0.1 kg using a portable electronic scale (SECA, Hamburg, Germany). The average of two measures for both height and weight was used to calculate BMI. BMI was then used to determine weight status. Weight status was classified into four categories based on age- and sex-specific percentiles from 2000 CDC growth charts (underweight: $<5^{th}$ percentile; normal weight: 5^{th} percentile to $<85^{th}$ percentile; overweight: 85^{th} percentile to $<95^{th}$ percentile; and obese: $\geq 95^{th}$ percentile).

Statistical Analyses.

To determine the influence of neighborhood socioeconomic environment and elements of the built environment on physical activity, a repeated-measures multilevel modeling framework with a spatial analysis extension will be employed. Specifically, this study will employ spatiotemporal regression modeling, a spatial analysis extension to traditional random effects models that accounts for temporal and spatial processes. This approach will allow the researchers to 1) account for the dependence of observations resulting from repeated measures and spatial clustering; and 2) incorporate information from adjacent neighborhood. The proposed analytic approach will enable the researchers to examine the influence of individual-level and area-level predictors on physical activity while simultaneously accounting for non-independence of the observations (197). This hybrid approach can account for both the hierarchical structure of the data and the effects of spatial clustering (i.e., autocorrelation).

Applying a spatial extension to the traditional regression modeling approach to address Aim 3 has several advantages. First, spatial models tend to perform better compared to standard regression models when examining data with a spatial structure. For instance, while standard and spatial models tend to perform similarly in estimating parameters for fixed effect, spatial models tend to outperform standard models in estimating parameters for random effects. As such, it has been suggested to adjust for both the nested hierarchy and spatial orientation of data to avoid biased and potentially inaccurate estimates of variance for random effects. Second, spatial models incorporate information from surrounding areas and allow for area-based parameter estimates to be influence by a group of neighbors. This approach can account for border issues resulting from census tract boundary lines. Notably, predictors of health outcomes such as socioeconomic environment context are not confined to census tracts borders and likely diffuse across administrative boundaries into nearby areas. Hence, the use of spatial analytic techniques to account for the influence of adjacent neighbors will allow for a more accurate estimate of the socioeconomic environment's influence on physical activity over time. Finally, accounting for both hierarchical and spatial processes in the regression model allows researchers to disentangle the random effect attributed to spatial processes from those attributed to non-spatial processes. In summary, applying a spatial analytic approach can account for the spatial autocorrelation between observations, reduce model bias due to residual confounding, and avoid artificially inflated statistical significance.

Objective 3A Spatial Dependence. Prior to examining the relationship between characteristics of the neighborhood environment and physical activity, we will examine sample descriptives and determine whether activity levels are spatial clustered within neighborhoods for each community. Preliminary maps will be generated to depict the distribution of observed physical activity levels across neighborhoods (i.e., census tracts). To determine whether spatial clustering exists, neighborhood residuals will be examined for spatial autocorrelation (i.e., clustering/dependence). In the presence of spatial clustering, residual values for neighborhoods located in close proximity will be more similar to each other than to observations farther away.

Prior to testing for spatial clustering, the criterion used to identify and weight neighboring areas must be established. We will employ a first-order neighbor structure using queen-based contiguity approach to identify census tracts neighboring one another. This is the most common approach to defining neighbors in spatial analyses. The term derives from the game of chess where the queen can move in any direction and implies that any two census tracts sharing a border in any direction will be considered neighbors (198). After selecting a neighbor structure, a spatial weights matrix based on binary connectivity will be developed. Using this weighting approach, neighboring census tracts will be coded as ‘1’ while census tracts that do not share a border (i.e., not identified as neighbors) will be coded as ‘0’ in the spatial weights matrix.

Next, we will formally test for spatial clustering within each community by calculating a Moran’s I statistic. Possible values for Moran’s I range from -1 to 1. Values near -1 represent perfect dispersion and indicate that dissimilar entities are located close to one another. For example, the distribution of squares on a checker board would have perfect dispersion with no similar colored squares sharing a border. Values near 1 represent spatial clustering and indicate that similar neighbors are grouped together. Building from the example above, perfect clustering would exist if all of the dark colored squares on the checker board were placed on one side of the board and all light-colored squares were placed on the opposite side. Finally, values of 0 represent spatial randomness. Under the null hypothesis, spatial randomness is expected (Moran’s I = 0) and no pattern would be evident.

Spatial clustering can be detected at the global and local level using the Moran’s I statistic. At the global level, the distribution or overall pattern of the outcome is examined across the entire study region. A significant Global Moran’s I indicates that spatial clustering is present within the specified study area; however, the statistic does not indicate where these differences or clusters exist. For this reason, local spatial clustering measures are often employed in the presence of a significant global measure to identify areas of local clustering or 'hotspots'. Local Moran's I, formally referred to as Local Indicators of Spatial Associations (LISA), produces location-specific statistics for each region (e.g., neighborhood) and will be used to identify local clusters or 'hotspots' of the outcome variable.

Global Moran's I will be calculated to examine spatial clustering across the entire study area to determine whether significant spatial autocorrelation is present. This global test is considered the best measure of spatial autocorrelation for aggregate data. An assumption of Moran's I includes normal distribution of the of the outcome variable across the study region with the same mean and variance observed for each region. If this assumption is violated, a Monte Carlo simulation for Moran's I will be conducted. In the presence of a significant global statistic, a local spatial autocorrelation test will be conducted to identify where clustering exists across each community in the study. The results from the spatial dependence tests will inform the analyses employed to address Objectives 3B.

Objective 3B Model Building. After determining whether spatial clustering exist at a global and local level, the next analytic step will be to: 1) examine the relationship between physical activity and neighborhood characteristics, and 2) determine the extent to which, if any, these characteristics explain the spatial variability in physical activity over time. To investigate the relationship between physical activity and the neighborhood socioeconomic environment over time, a four-level (time, individual, neighborhood, spatial processes) spatiotemporal regression model will be conducted. Level 1 will account for time. Level 2 variables will include the individual-level characteristics age (years), sex (two levels: male [referent] and female), race/ethnicity (four levels: Non-Hispanic White [referent], Non-Hispanic Black, Hispanic, and Other), parent education (two levels: ≤ high school diploma and > high school [referent]), and weight status (three levels: underweight/normal [referent], overweight, and obese). Level 3 variables will include a measure of the neighborhood socioeconomic environment (index score). Level 4 variables will include neighbor information from the spatial weights matrix.

First, bivariate associations between each predictor variable (i.e. independent and covariate variables) and all expressions of the physical activity will be examined. Next, a series of regression models will be generated for each expression of the outcome variable. Specifically, the following models will be produced to address Objective 3B: (1) empty model without any explanatory variables predicting physical activity (Null Model); (2) single-level model incorporating time (Model 1); (3) model including time and neighborhood socioeconomic environment variables (Model 2); (4) model including time and neighborhood socioeconomic environment with a spatial extension (Model 3 -Spatial Model). Lastly, adolescent covariates will be added to the model to examine these relationships in a fully adjusted model.

Objective 3C Model Building. Next, an interaction term will be introduced to the model from Objective 3B to examine the potential moderating effect of elements of the built environment on the relationship between neighborhood socioeconomic environment and physical activity over time. The potential moderation effects will be examined for all expressions of the outcome variable. To maintain a parsimonious model, only interactions remaining significant in the full model will be retained. If the interaction term is significant, estimate statements will be generated to examine the effect of neighborhood socioeconomic environment on physical activity across varying built environments. For ease of interpretation, neighborhood socioeconomic and built environment variables may also be examined as categorical variables. The amount of spatial variability in physical activity explained by neighborhood variables over time will be calculated from the final model. The assumptions (i.e., independence, normality) of each statistical model will be assessed.

Model Fit. Statistical significance and model fit will be examined for each model. For each model, the mean regression coefficients (β) and their 95% confidence intervals will be estimated. Using maximum likelihood estimation methods, Akaike's Information Criterion (AIC) will be used to assess model fit. Lower values of AIC indicate better model fit. An alpha level less than 0.05 will denote statistical significance for two-sided statistical tests. All analyses will be conducted in R software using the spdep, glm, and/or bugs functions. If model convergence is an issue, Bayesian inference will be considered in place of maximum likelihood estimation methods. While both estimation methods have been developed for multilevel and spatial models, Bayesian approach tends to better handle complex hierarchical data structures. However, this approach also introduces additional bias into the model. If Bayesian inference estimation methods are employed, models will be fit using Monte Carlo Markov Chain (MCMC) methods; Gibbs sampler will be used to estimate fixed and random effects; priors will be set to non-informative; and model fit will be assessed using the Deviance Information Criterion (DIC).

Table 6.1. Description of studies selected for the review: Neighborhood Socioeconomic Environment, Physical Fitness Components, and Physical Activity.

				Outcome		**Neighborhood Socioeconomic Position**		**Covariates**		
Study	**Sample**	**Country**	**Study Design**	**Outcome**	**Method of Assessment**	**Variable(s)**	**Unit of Analysis**	**Environ-ment**	**Individual**	**Key Findings**
PHYSICAL FITNESS										
Gay et al. (2016)	2,126 public schools	US, Georgia	Cross-sectional	Physical Fitness (5 components) - BMI - Aerobic fitness - Abdominal strength - Upper body strength - Flexibility	FITNESS-GRAM	Social Vulnerability Index (SVI): 4 themes/14 variables: - Socioeconomic, - Household Composition, - Minority Status and Language, - Housing and Transportation	Census tract	--	--	School SVI associated with all fitness measures for boys and girls; higher SVI = lower proportion of youth in HFZ SVI themes explained the most variability in BMI (boys: 11.5%; girls: 16.3%) & aerobic fitness (boys: 26.6%; girls: 20.8%)
WEIGHT-RELATED OUTCOMES										
Alvarado (2016)	11,499 youth (2-18 yo)	US	Longitud-inal	Obesity (age- and sex-specific BMI percentile ≥95)	Parent-reported or direct measurement by interviewer (depending on child age)	Neighborhood Disadvantage Index (7 variables; quintiles): Proportion of the population: - at or below 100% poverty threshold - unemployed - out of labor force	Census tracts (1990, 2000, 2010)	---	Age Sex Race/ethnicity Mother/household characteristics: - Obese - Unemployed - No. of children	NBH deprivation is associated with increased risk of obesity among youth Age and sex moderate this relationship; NBH disadvantage has stronger impact on: - adolescents vs. children - girls vs. boys

						- with Bachelor's degree or higher (reverse coded) - managers and professional position (reverse coded) - Median income (reverse coded) - Median housing value (reverse coded) -			- Single parent - Education level - Foreign born - Income - Poverty status	
Grow et al. (2010)	8,616 youth (6-18 yo) 369 census tracts	US (King County, WA)	Cross-sectional	Obesity (BMI $\geq$95th percentile)	Height and weight measured in clinical setting	5 variables: - median household income - home ownership - adult female education level - single parent households - race (% white)	Census tract (2000)	----	Age Sex Medical Insurance Type	Child obesity risk was significantly associated with each census tract variable in the expected direction SES/race variables at NBH level explained ~24% of geographic variability in child obesity Relationship between broader social and economic context and obesity
Oliver et al. (2008)	2,152 youth (2-11yo)	Canada	Longitudinal (5 cycles; biannual; 1994-2002)	BMI	Parent-reported height and weight	Neighborhood income: proportion of non-institutionalized population living below the low-income cut-off; (3 groups): - Least poor - Middle - Most poor	Enumeration area (1996 census)	---	Age Sex Income Education Family structure	Early neighborhood environment was found to influence child BMI percentile Controlling for individual/family factors, living in most poor neighborhood was associated with higher BMI percentile over time

Nau et al. (2015)	163,473 youth (3-18 yo)	US 1,288 communities in PA	Longitudinal	BMI	Height and weight measured in clinical setting	Community Socioeconomic Deprivation (CSD) Index (6 variables; quintiles): Proportion of the population: - With less than high school - Unemployed - Not in labor force - In poverty - Receiving public assistance - Households without a car	Census tract (1990, 2000; ACS 2005-2009)	---	Age Sex Race/ Ethnicity	Higher CSD associated with higher BMI at age 10.7 and with more rapid growth of BMI over time. The association between CSD and BMI varied across the age span and by degree of CSD. Initial acceleration in BMI steeper in children living in neighborhood with higher CSD.
Nevill et al. (2015)	8,053 youth (10-16yo)	England	Cross-sectional	Waist circumference Body mass (kg)	Objectively measured by trained research staff	Index of Multiple Deprivation (IMD)	Small-area geographic units (equivalent to U.S. census tracts)	--	Hip circumference Stature Age Sex Cardiorespiratory fitness (20m shuttle run) Physical activity (self-report)	Strong association between weight status and neighborhood deprivation, after controlling for demographic variables. The addition of fitness and physical activity into the models significantly reduced (WC) or eliminated (BM) the relationship suggesting that youth from more deprived neighborhoods were less fit & active Findings suggest that increased physical activity and fitness in youth residing in deprived neighborhoods may

										reduce disparities in overweight and obesity.
Powell et al. (2012)	8,984 youth (12-17yo)	US	Cross-sectional	BMI (disparities across race/ethnicity groups)	Self-reported height and weight	Median household income (2000 census)	County level	Food store, restaurant, and PA-related outlet density	Sex Age Race/ethnicity Parent Income Family structure Mothers work status Urbanicity	Full model explained BMI disparities: - 44% B-W female - 62% H-W female - 63% B-W male - 78% H-W male Neighborhood economic contextual factors explained: - 13% B-W female - 8% H-W female - 28% B-W male - 38% H-W male Neighborhood factors more important for males; home/individual factors for females. Neighborhood median household income was negatively associated with BMI among minorities
Rossen (2014)	17,100 youth (2-18yo)	US	Cross-sectional	Obese/ Overweight Odds of obesity (age- and sex-specific BMI percentile ≥95)	NHANES mobile examination component; objective measure	Neighborhood Socioeconomic Index (6 variables): - % adults over 25 with less than a high	Census tract (2000)	--	Age Age^2 Sex Race/ethnicity SES: household income-to-poverty ratio; caregiver	After controlling for area deprivation, racial/ethnic disparities in obesity attenuated by: - 74% in Black children;

				Odds of overweight (age- and sex-specific BMI percentile ≥85)		school education; - % mean over 16yrs unemployed; - % families below Federal Poverty Threshold; - % household receiving public assistance; - % females headed household with children; - % median household income			education & marital status	- 49% in Hispanic children Significant interaction between area deprivation and individual-level income: Income was protective against obesity for children living in low-deprivation areas (high SES), BUT positively associated with obesity for in high-deprivation areas (low SES) Area deprivation associated with higher odds of obesity but only among children living above the poverty threshold
Schule et al. (2016)	3,499 children (5-7 yo)	Germany 18 school enrollment zones in Munich	Cross-sectional	Obese/ Overweight	Height and weight objectively measured by trained staff	Neighborhood Socio-economic Position Index (5 variables): Proportion residents/ households: - no citizenship - citizenship & migration background - single parent - lower education - vocational training	School enrollment districts	Ages-specific playground space (GIS) Park availability (GIS) Perceptions of neighborhood environment	Age Sex Parent education Household income Parent employed Household crowding Nationality Birth weight Parent BMI	Main risk factors for overweight/obese: low parent education; parental weight status; high birth weight; living in multiple dwellings Contextual neighborhood socioeconomic factors, age-specific public playgrounds and park availability showed NO independent association with weight status

Sharifi et al. (2016)	44,810 youth (4-18yo)	US 14 pediatric clinics in MA	Cross-sectional	BMI z-score	Height and weight measured in clinical setting	2 variables: - median household income (2009 dollars) - % adults without high school diploma	Census tract; (ACS 2006-2010)	Recreational open space density Intersection density Residential density Land use mix	Race/ethnicity Height Weight Sex DOB/Age	Observed BMI disparities attenuated by: 1) Neighborhood SES: 30.2% black, 26.3% Hispanic compared to White 2) Physical activity environment: 7.0% & 5.3% 3) fully adjusted model: 27.9% & 23.7% BMI differences persisted in fully adjusted model
			Longitudinal	Change in BMI z-score (measured 2+ times 1 year apart)	Height and weight; measured in clinical setting					Change in BMI was significantly greater among black compared to white youth; not substantially attenuated by neighborhood level variables; No difference between Hispanic and white youth
Singh et al. (2010)	44,101 youth (10-17yo)	US	Cross-sectional	Obese/ Overweight	Parent-reported height and weight	NBH Socioeconomic Condition Index (4 variables): - Safety - Presence of garbage/litter - Poor or dilapidated housing - vandalism	Parent-reported perception of neighbor-hood	Index: - Access to sidewalk and walking paths - Parks and playgrounds - Recreation centers, community centers, etc. - Presence of library	Age Sex Race/ethnicity Household composition Metropolitan Household poverty status Parent education TV viewing time Computer use **Physical activity**	Odds of overweight/ obesity were 20-60% higher in neighborhoods with most unfavorable social and built environment conditions Built environment had a stronger influence weight status in younger children and girls Youth living in unfavorable social

								or bookmobile		conditions were 50% more likely to be physical inactive; youth in least health promoting neighborhoods with fewest amenities were 61% more likely to be physical inactivity
PHYSICAL ACTIVITY OUTCOMES										
Boone-Heinonen et al. (2010)	17,294 youth (11-22 yo) Grades 7-12	US	Cross-sectional	Moderate-to-vigorous physical activity (MVPA)	Self-reported total weekly bouts of MVPA	Advantageous economic environment (index) - Low proportion of residents living below poverty - high proportion of residents with college degree or greater - High median household income Disadvantageous social environment (index) - High proportion of minority residents - High crime rate (county level) - High proportion of renters	Census tract	Built environment index (1K or 3K buffer): - homogenous landscape - development intensity with high pay facility count - development intensity with high public facility count	Age Race Parent education Annual household income U.S. region	Adolescents living in high neighborhood SES quartile accumulated 7% more MVPA than lowest neighborhood SES quartile in fully adjusted model Built environment and neighborhood SES factors were both strongly associated with MVPA; neighborhood SES environment may confound relationship between built environment and MVPA

De Meester et al. (2012)	637 youth (13-15 yo) 32 Neigh-borhoods	Belgium	Cross-sectional	Physical activity	Objective: Accelerometry - Avg. activity level (counts/min) - MVPA (avg. min/day) Subjective: self-report - Leisure PA - Active transport - Sport participation	Median annual household income (dichotomous: low/ high) - Low neighborhood SES (2nd-4th decile) - High neighborhood SES (7th-9th decile)	Census tract	Walkability Index	Age Gender Nationality SES (Parent education & employment status)	Association between neighborhood walkability and physical activity varied by neighborhood SES (association held only for those living in low neighborhood SES) No association between self-reported physical activity and neighborhood SES or walkability; walking for transport negatively associated with neighborhood SES Gender did not moderate relationship between neighborhood SES, neighborhood walkability, and physical activity
Lee et al. (2002)	10,645 youth (12-21 yo)	US	Cross-sectional	Physical activity	Self-reported: Number of days per week participated in physical activity (none/some)	Neighborhood SES (6 variables): - Family income, Poverty, Education, Housing value, Crowded housing, Blue collar Social disorganization (6 variables): - Mobility, Unemployment,	Census tract	---	Age Sex Race/ethnicity Parent education attainment Income-to-needs ratio	Low SES associated with less physical activity; Hispanics accumulated less physical activity Neighborhood SES characteristics were not associated with physical activity levels.

						Housing tenure, Female headship, Poor female headship, Divorced Racial/ethnic minority concentration Urbanization				
Pabayo et al. (2014)	1,878 youth (14-19 yo) 38 Neigh-borhoods	US (Boston, Massachusetts)	Cross-sectional	Physical Inactivity	Self-report (survey): No participation in PA in previous week	Economic deprivation index: Proportion of residents/ households: - below poverty level; on public assistance; income ≤$25K; income >$100K (reverse coded) Social fragmentation Index: Proportion of residents/ households: - lived in same house <5yrs; vacant housing units; owner-occupied housing (reverse coded)	Census tract (2010)	Social Cohesion Neighborhood Disorder Neighborhood Safety	Age Nativity Race/ethnicity	High social fragmentation associated with increased likelihood of physical inactivity No other neighborhood exposures were associated with physical inactivity

WEIGHT-RELATED AND PHYSICAL ACTIVITY OUTCOMES										
Carroll-Scott et al. (2013)	1,048 youth Grades 5-6 25 census tracts; avg. 42 students	US New Haven, CT	Cross-sectional	BMI	Objective: height and weight measured by trained research assistant	Concentrated Disadvantage Index: - % of residents: living below poverty line, unemployed, households receiving public assistance, female headed households Concentrated Advantage Index: - % of residents: 25+ years with college education, households with high income, residents who hold executive or professional jobs headed households	Census tract	Built Environment: - perception of park access - walking distance to food and park - tract-level count: grocery, convenience, fast food, and park Neighborhood Social Environment: - neighbor-hood social ties - neighbor-hood safety scale	Age Race/ethnicity Sex Free/reduced lunch status	BMI: significantly associated with living >1/2 mile from nearest grocery store and living in neighborhood with more property crime
				Physical Activity	Self-report (PACE Survey): Number of days per week exercise 30+ minutes					Physical Activity: associated with greater perceived access to parks, playgrounds, and gyms and more neighborhood social ties Built and social environment associated with weight and physical activity; neighborhood SES was not.
Janssen et al. (2006)	6,684 youth Grades 6-10 169 schools	Canada	Cross-sectional	Obesity	BMI; self-reported height and weight	Area-level SES (3 variables; quintiles) - Unemployment rate	5 km radius around school (2001 census tracts)	---	SES (material wealth & perceived family wealth)	Obesity: directly associated with physical inactivity and 2 SES measures (material wealth & unemployment rate); not associated with unhealthy eating

						- % adults with less than high school education - Average employment income from head of household *Variables - quartiles*				Individual and area-level SES measures were independently related to obesity
				Physical Inactivity	Self-report; No. of days per week physically active at least 60 minutes					Physical Inactivity: associated with individual-level SES
Nelson et al. (2006)	20,745 youth Grades 7-12	US	Cross-sectional	Overweight (BMI $\geq 95^{th}$ percentile)	Self-report: height and weight	Neighborhood SES Variables: - Median household income - Proportion resident 25+ years with college education - Proportion minority residents - Poverty (<185%) - Housing units (renters) - Mobility - Proportion working in county of residence *Combined neighborhood SES & built environment variables to create 6 neighborhood types*	Block group	Variables (3km buffer) - Crime per 100,000 - PA facilities - Walkability - Road type	Age Race/ethnicity Individual SES	Overweight: compared to new suburban developments those living in 1.) rural working class; 2.) exurban, and 3.) mixed race urban NBHs were 30-40% more likely to be overweight
				Physical activity	Self-report (survey): bouts per week of MVPA					Physical activity: youth living in older suburbs were more likely to be active than new suburbs
Slater et al. (2010)	10,620-36,929 youth (13-16 yo)	US	Repeated cross-sectional	Physical activity - VPA	Self-reported	Median annual household income (2000 census)	Census tract	# physical activity outlets per 10,000 residents	Sex Grade Race/Ethnicity Student employment	Increased local area physical activity outlets associated with higher physical activity Lower neighborhood safety associated with

	Grades 8 and 10 420 schools			- Sport participation - PA participation BMI / Obesity				Ratio of higher road classes to all other roads Compactness index (density, street connectivity) --------- Perceived environment	Student weekly income Parent education Mother work status School type (public vs. private) Region Year of data collection	lower activity, higher BMI/obesity; Physical disorder associated with decreased sport participation, increased BMI/obesity Neighborhood compactness associated with lower BMI/obesity Neighborhood SES associated with weight but not physical activity
Villanueva et al. (2015)	727 youth (6-15 yo) 119 Neighbor-hoods	Spain (Madrid)	Cross-sectional	Obesity	Height and weight objectively measured	2 variables: - unemployment rate (indicator of material deprivation) - mean habitable home surface area (indicator of wealth) *grouped into quartiles*	Census tract (2001)	Number of retail shops, supermarkets, and sport facilities per 1,000 population	Household SES: - primary household earners education level and professional qualifications	Worse household socioeconomic indicators associated with higher prevalence of obesity; built environment had no influence
				Physical Inactivity	Parent-reported activity: none or some					Physical inactivity was NOT related to neighborhood socioeconomic context or sport facilities
Voorhees et at. (2009)	1,545 girls in grade 6	US	Cross-sectional	BMI	Height and weight objectively measured	Townsend Index: - level of car ownership, household tenure; unemployment,	½ mile buffer around home residence; Weighted average	School SES (% of student population receiving free/reduced lunch)	Race/Ethnicity Parent Education Parent Employment	BMI: Lower individual and neighborhood indicators of SES were associated with higher BMI

				Non-School Physical Activity Physical activity type & context	Acceleromete r 3DPAR Survey	and overcrowded living conditions	of block groups in buffer		Free/Reduced Lunch Status	Physical activity: no association with any SES measure and physical activity observed Qualitative differences in type and location of activity between high vs. low neighborhood SES
Wardle et al. (2003)	4,320 youth (11-12 yo) 36 schools	UK (London)	Cross-sectional	Obesity	Objective measure of height and weight; BMI	Townsend Index: - level of car ownership, household tenure - unemployment, and overcrowded living conditions	Census/di strict level	-----	Sex Age Ethnicity	Obesity: the odds were 1.7 times higher among deprived boys; girls exhibited similar trend (not significant)
				Physical activity	Self-reported engagement in physical activity on weekend: Y/N					Physical activity: deprived boys were less activity (not sig); significant linear trend observed among girls

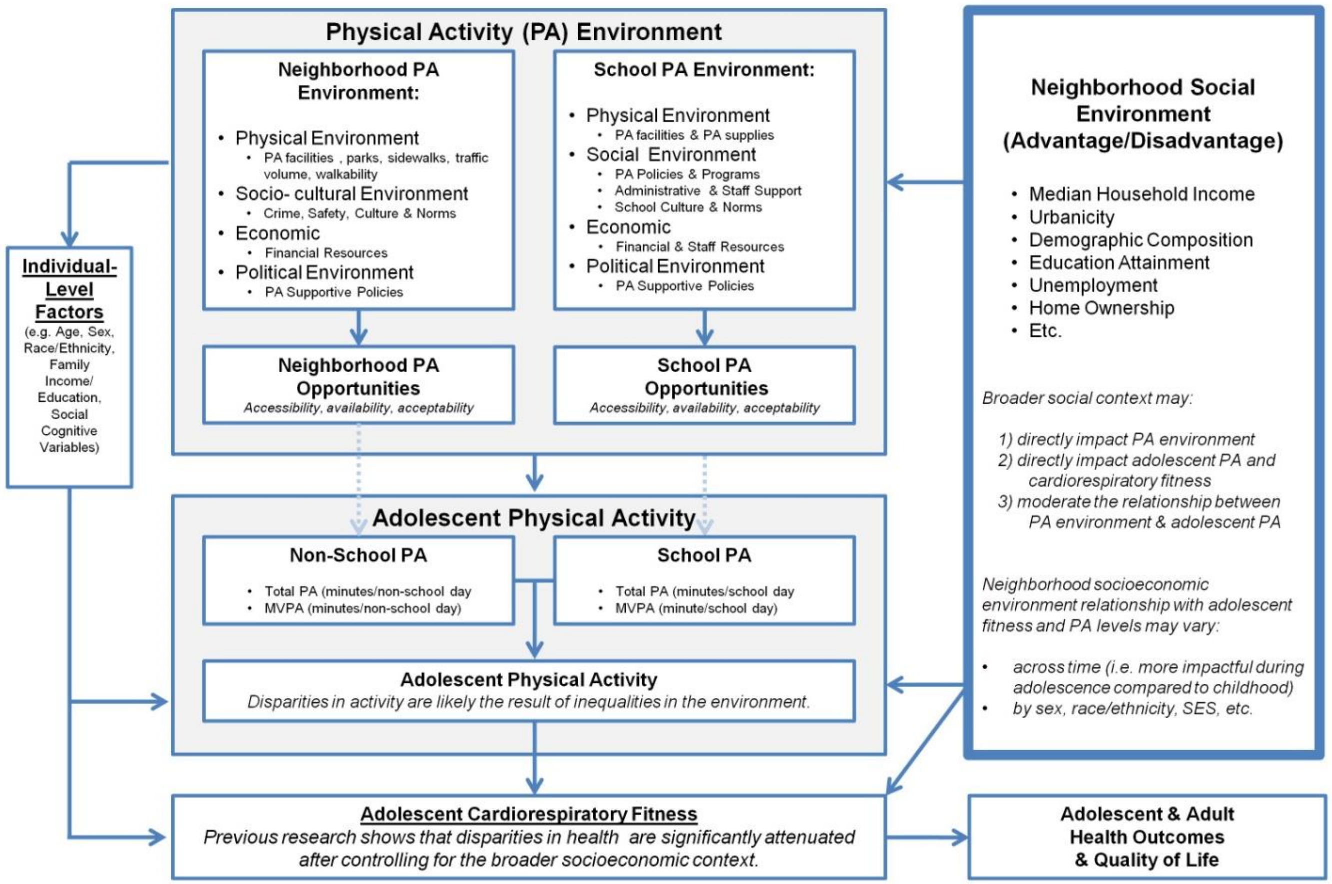

Figure 6.1. Conceptual model illustrating the hypothesized influence of neighborhood socioeconomic environment on adolescent physical activity and cardiorespiratory fitness levels (Adapted from Schreier & Chen 2013 and Kremers et al. 2006.)

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